

calcareous soils



FOREWORD

This Report on the FAO/UNDP Regional Seminar on Reclamation and Management of Calcareous Soils is the third in a series of Reports on seminars held in the Near East covering problems of practical importance to agricultural development, such as amelioration of saline and waterlogged soils and effective use of irrigation water at the farm level.

Realizing the extensive occurrence of calcareous soils in all the countries of the Near East region and their specific characteristics that entail special soil and water management practices, the FAO Land and Water Use Commission felt the need to hold a seminar for the identification of the properties and related problems of calcareous soils as well as to find practical solutions leading to a better utilization of these land resources.

The Seminar succeeded in bringing together senior governmental officers from the region and high level experts to review and discuss recent scientific and technical activities in the field of reclamation and management of calcareous soils. The recommendations adopted by the Seminar did not only call for more research on the identification and utilization of calcareous soils but also for the extension of the available information to the users of these soils.

The implementation of the suggested research activities could be carried out within the framework of the Regional Applied Research Programme for Land and Water Use in the Near East. It is hoped that the technical material included in this Report and the findings of the Seminar will lead to a better understanding of the characteristics and more efficient utilization of the calcareous soils not only in the countries of the Near East but wherever they occur under similar climatic conditions.

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I. INTRODUCTION, SUMMARY OF RECOMMENDATIONS AND ACKNOWLEDGEMENTS

1. Introduction

The FAO/UNDP Regional Seminar on Reclamation and Management of Calcareous Soils was held in Cairo from 27 November to 2 December 1972 at the kind invitation of the Government of the Arab Republic of Egypt.

In 1969 the FAO Regional Commission on Land and Water Use in the Near East recommended that FAO should start an applied research programme in the region concentrating on four central activities which cover the main problems having a detrimental or retarding effect on agricultural development in the region. These problems concern:

- Reclamation, improvement and management of salt affected soils, including where applicable the control of waterlogging; (FAO/UNDP Regional Seminar on Methods of Amelioration of Saline and Waterlogged Soils, Baghdad, Iraq, 5-14 December 1970);
- Reclamation, improvement and management of calcareous soils; (FAO/UNDP Regional Seminar on Reclamation and Management of Calcareous Soils, Cairo, Egypt, 27 November - 2 December 1972);
- Reclamation, improvement and management of sandy soils; (provisionally: FAO/UNDP Regional Seminar on Reclamation and Management of Sandy Soils, Nicosia, Cyprus, December 1973);
- Determination of the most economic use of irrigation water, taking into account consumptive use, application efficiency, crops and cropping patterns; (FAO/UNDP Regional Seminar on Effective Use of Irrigation Water at the Farm Level, Damascus, Syrian Arab Republic, 7-13 December 1971).

The main objective of the Seminar was to bring together senior government officials and high level experts to review and discuss recent scientific and technical activities in the field of reclamation and management of calcareous soils. Also to identify problems of regional interest and to suggest applied research programmes on calcareous soils within the framework of the Regional Applied Research project on land and water use in the Near East.

The Seminar was attended by 47 participants from 11 member countries of the FAO Regional Commission on Land and Water Use in the Near East, 17 participants from 8 FAO/UNDP projects in the region, 13 observers from non-member countries of the Commission and international and national organizations and several FAO staff from the Regional Office in Cairo and from Headquarters. The full List of Participants is attached as Annex 2.

This Report deals first with the invited papers on technical subjects concerned with the reclamation, improvement and management of calcareous soils, which form Chapter III. These are, in Chapter IV, followed by statements from country participants concerning conditions in their own countries and then as Chapter V there is a group of four supplementary papers on work and studies carried out on calcareous soils in countries either in the region or bordering it. Chapter VI then deals with the recommendations made during the Seminar. The Agenda is attached as Annex 1.

2. Summary of Recommendations

The following main recommendations were made by the Seminar, that:-

- (i) the information available on the effective use of calcareous soils be compiled and exchanged between the countries of the region;

- (ii) the concept of calcareous soils be more precisely defined and that the description of these soils be expressed in standardized terminology taking into account the amount, form and distribution of CaCO_3 and its effect on the physical, chemical and mineralogical characteristics of these soils;
- (iii) the survey of calcareous soils be pursued and in order to allow for an exchange of experience the classification system used for mapping be correlated;
- (iv) the relationship between soil properties and their effect on crop growth and soil and water management practices be established under specific environmental conditions and be used for land use evaluation purposes at different levels;
- (v) a comprehensive soil testing system be applied for recommending fertilizer applications and that the calibration of each test be checked under local conditions with special reference to calcareous soils;
- (vi) further research on P nutrition and its economic application be carried out on the basis of new concepts of P supply to roots, and that research be conducted on the N balance under different cropping systems, on the supply, form, availability and toxicity of micronutrients, on the role of organic matter with regard to structural stability and availability of nutrients;
- (vii) specific morphological and physical characteristics of calcareous soils be taken into consideration when irrigation is practised; irrigation methods other than the conventional ones be investigated with a view to determining the susceptibility of calcareous soils to salinization; field treatments be investigated to prevent the effects of surface crusting; the machinery needed for tillage operations be tested in relation to the soil properties and economy; crops and varieties be selected which are adapted to calcareous soil conditions;
- (viii) extension programmes be strengthened and that research efforts be aimed toward the solution of practical problems;
- (ix) the implementation of the above recommendations be carried out in the framework of the FAO/UNDP Regional Applied Research Programme for Land and Water Use in the Near East. The Seminar expressed the hope that this programme which is now in its first phase will be further developed with the support of the UNDP and further recommends that FAO use its good offices in expediting early action in this respect.

These recommendations will be presented to the Fourth Session of the FAO Regional Commission on Land and Water Use in the Near East which may possibly be held in December 1973 in Cyprus.

3. Acknowledgements

The Food and Agriculture Organization of the United Nations wishes to express its gratitude to the Government of the Arab Republic of Egypt, the Ministry of Foreign Affairs, the Ministry of Agriculture and Land Reclamation, the Arab Socialist Union and all other organizations and officials for their excellent cooperation and generous hospitality. FAO also wishes to express its thanks for the most interesting field excursion which was organized by several institutions and officers concerned with agriculture in Egypt.

Special mention should be made of the United Nations and the United Nations Development Programme who contributed materially to the running of the Seminar.

FAO wishes to record its appreciation of the support given by the countries of the Near East who participated in the Seminar.

Finally, special thanks are due to His Excellency Dr. M.M. Elgabaly, Minister of Agriculture and Land Reclamation, who took such an active part in the Seminar, not only by opening it but also by delivering one of the main lectures; thanks are also expressed to the Director of the Seminar, Dr. Rifki Anwar, Head of the Egyptian Delegation, for the firm control and authority with which he guided the proceedings and to Dr. M. Bashir Choudri of Pakistan, Vice-Chairman of the Seminar and Chairman of the Drafting Committee.

II. OPENING SPEECHES

1. His Excellency Dr. M.M. Elgabaly, Minister of Agriculture and Land Reclamation

On behalf of the Egyptian Government, His Excellency Dr. M.M. Elgabaly welcomed members of the Food and Agriculture Organization, the UNDP Resident Representative and participants from the countries of the region and others attending the Seminar. He thanked FAO for organizing and servicing the meeting. He stated that agriculture started in this region in the alluvial plains. When the land was irrigated, problems such as salinity developed and they were tackled scientifically. Due to population pressure and the rise in living standards, the countries of the region started to bring new lands under plough, most of which were calcareous. They were thus faced with numerous problems for which no definite solution was available and they tried to solve them by trial and error.

Realising the importance of these soils and the need for applied research on their problems, FAO is organizing this Seminar. His Excellency then enumerated the main problems of these soils which are: first, the high CaCO_3 content and its effect on soil fertility and nutrient availability; secondly, soil crusting and its effect on seedling emergence and crop stand and thirdly, the low available moisture range. He was confident that countries in the region, in cooperation with FAO, would succeed in finding solutions to these problems.

He said that through the exchange of ideas and experience during the meeting, recent developments in this field could be expressed, discussed and, if suitable, adopted for application in the region and also an applied research programme could be properly planned. By coordinating their activities they would be able to find expeditiously solutions to the basic problems of these soils.

2. Dr. A.F. Moursi, Deputy Regional Representative of FAO in the Near East

Dr. Moursi, Deputy FAO Regional Representative, on behalf of the Director-General of FAO welcomed the participants to the Seminar. He expressed appreciation to the Government of Egypt for hospitality to the Seminar and to UNDP for financing it. Dr. Moursi recalled that this Seminar had been organized upon recommendation of the Near East Commission for Land and Water Use and was third in a series of four devoted to specific land and water management problems in the Near East.

3. Mr. V. Pavioic, Resident Representative of the UNDP in Egypt

Mr. V. Pavioic, Resident Representative of the UNDP in Egypt expressed his appreciation to Dr. Elgabaly for presiding over the opening session of the Seminar. His presence reflected the interest of the Government of Egypt in development of calcareous soils. Mr. Pavioic stressed that the possibilities for horizontal land expansion are very limited so that increased attention needs to be given to soils already under cultivation. It is for this reason that UNDP supports soils studies which form a basis for agricultural development planning.

III. WORKING PAPERS

III.1. MORPHOLOGY AND DISTRIBUTION OF CALCAREOUS SOILS IN THE MEDITERRANEAN AND DESERT REGIONS

by

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SUMMARY

Three characteristics permit the main types of calcareous soils in the desert, arid and Mediterranean countries to be defined.

- 1) The development of the Bca horizon. This horizon can be:
 - a) absent;
 - b) weakly differentiated; the accumulation is diffuse with, sometimes, some pseudo-mycellium (carbonate content: < 40%);
 - c) moderately differentiated: Bca contains diffuse and nodular carbonate; nodules can be soft or hard (carbonate content: < 60%);
 - d) very well differentiated: part of the Bca is an "encroûtement" (encrustation); this encrustation (carbonate content: > 60%) can be:
 - i) a non-platy encrustation (massive or nodular);
 - ii) a platy encrustation; there are two types:
 - calcareous crust, overlying a non-platy encrustation
 - compact slab, overlying a calcareous crust and a non-platy encrustation;
 - iii) a laminated encrustation; it is the ribboned pellicule that comes on the top of the platy or non-platy encrustation.
- 2) The carbonate content, texture and thickness of the A horizon.

Note: This paper was originally submitted in French.
version was presented during the Seminar.

The following English

- 3) The colour and structure of the epipedon. The epipedon can be:
- a) dark, with fine and stable structure;
 - b) clear;
 - c) very clear, with weak and unstable structure.

1.1. Introduction

In countries with Mediterranean, arid and desert climates, soils containing calcium carbonate in one or several of their horizons are frequent.

There are two main reasons for this:

The first is the rocks: in these regions they are frequently calcareous, or simply rich in calcium (for example the basalts).

The second is the climate: the frequent alternation of wet and dry periods and the existence of a long dry season are not favourable to deep leaching of the solutions in the soils.

The denominations and classifications of these soils are very varied. I do not want to discuss this question but only to remind you of the names of these soils in three main classification systems:

- in the French system, the Mediterranean and desert calcareous soils are classified as: "peu évolués" (poorly developed) soils, calcimagnésiques soils, isohumiques soils or as Mediterranean fersiallitic red or brown soils.
- according to the U.S.A. classification, these soils are xerochrepts (inceptisols), argids or orthids (aridisols), rendolls or xerolls (mollisols), xeralfs (alfisols).
- according to the key of the FAO/Unesco Soil Map of the World, the calcareous soils of the Mediterranean and desert countries can be fluvisols, rendzinas, yermosols, xerosols, castanozems or cambisols.

1.2. Morphology of the Calcareous Profile

Three main horizons can be distinguished from observation and study of the distribution of the carbonates in these soils:

- In the middle part of the soils there is an horizon where the content of calcium carbonate is higher than in those situated above and below. It is an horizon of calcium carbonate accumulation, i.e. a Bca; and in it the carbonate is generally partially visible because it is partially concentrated.
- Above this Bca, the carbonate is less abundant and it can even be absent. Therefore from the carbonate this upper horizon is an A horizon.
- Below is the C horizon, that is the parent material, which can be calcareous or not.

The distribution of the carbonate in these three horizons define what can be called the calcareous profile. This calcareous profile is the most important characteristic of these soils which are, in fact, soils with a differentiated calcareous profile. This is the name given to these soils in this paper and the aim is to give and to recall some data about the characteristics and the distribution of these soils however, without going into discussion of the names and of the classification of these soils.

The Bca horizon of these soils is the most important one and a study of the morphological organization of these soils must be started with the study of the Bca horizons. According to morphology of this horizon, three main types of profile are distinguishable.

- First there are soils with a weak differentiated calcareous profile. In these soils the thickness of the Bca horizon is slight, only 20 to about 50 centimeters; the development is weak, i.e. the content of carbonate in this horizon is not very much higher than in the A and C horizons (only some 10 %). Furthermore, the distribution of carbonate in the Bca horizon is diffuse or occasionally concentrated in some pseudo-mycelium.

The accumulation of the calcium carbonate in this type of Bca is in the form of fine particles. The upper and lower limits of this type of Bca horizon are diffuse and it is frequently difficult to recognize the presence of the horizon in the profile. In general it has a clearer colour than the horizons situated above and below, but sometimes it is necessary to wait the results of the analysis to know the presence of the accumulation.

- Secondly there are soils with a Bca horizon in which the calcium carbonate accumulated is partially concentrated. Calcium carbonate concentration are present and they can be soft or hard. When they are hard they are called nodules. These soils have a moderately differentiated calcareous profile. The upper and the lower limits of this Bca horizon are generally diffuse. The content of carbonate does not exceed 50 to 60% and the thickness of the horizon can vary from 20 to almost 100 cm.
- The third type of soils has a Bca horizon in which the carbonate form in a part of the horizon is a continuous layer known in French as an "encroûtement calcaire". It is almost equivalent, though not exactly, to the American petrocalcic horizon. The term "encroûtement" can be translated lime crusting or calcareous encrustation. The soils with this type of Bca have a very well differentiated calcareous profile.

There are several types of crusting (encrustation) :

- (i) Non platy lime crusting with two sub types:
 - a) characterized by a massive, fairly continuous structure or also by a fine polyhedral structure.
 - b) marked by a nodular and polyhedral structure; the nodular structure is due to the presence of calcium carbonate nodules. The content of calcium carbonate is generally high, between 50 and 80 %.
- (ii) Platy structure lime crusting, also with two sub types:
 - a) "croûte calcaire" known in English as calcareous crust. This crust is usually situated above a non platy lime crusting. This type of Bca horizon has the characteristic of being a clear, very distinct platy, laminar structure. The content of calcium carbonate is generally high: 60 to 90%. However, if the parent material is quartz sand (sand dune, sand stone), the calcareous crust may contain only about 40% carbonate.

- b) "dalle compacte" which is translated in English as compact slab. This is the transformation of the calcareous crust into very hard, stone-like, platy elements. If there is a slab it is generally situated on top of a calcareous crust. The slab is usually very rich in carbonate: between 70 and 90%. The colour is salmon pink.
- (iii) Very fine laminated pellicule which frequently covers the top of the lime crusting and particularly the top of the platy lime crusting. The French name of "pellicule rubanée" may be translated as ribboned pellicule (thin lime pan). It is always a thin formation of some millimetres to one or two centimetres, is frequently very hard and always rich in carbonate - more than 70%. The colour is white or salmon, sometimes with darker lamellae.

To summarize, the Bca horizon of calcareous soils can be :

- First, a diffuse accumulation with or without pseudo-mycelium; in this case the calcareous profile is weakly differentiated.
- Secondly, the Bca horizon contains soft concentrations or nodules (hard concentrations) throughout the thickness of the horizon or only in part of it; the calcareous profile is moderately differentiated.
- Thirdly, part of the Bca horizon is a lime crusting, the thickness of which varies from 10 cm to more than 2 metres. This calcareous profile is very well differentiated.

The lime crusting can be :

- non platy,
- platy, i.e. a crust usually surmounting a non platy lime crusting,
- a compact slab situated on a crust and on a non platy lime crusting.

In the three cases a ribboned pellicule can cover the top of the Bca horizon.

Two points should be noted. Some calcareous soils have no Bca, no accumulation of carbonate and this occurs in two cases. In the first there is no differentiation in the calcareous profile; the content of carbonate is the same from the top to the base of the soil. This is found in young soils. In the second case the calcareous profile is weakly differentiated and there is a progressive increase in the carbonate content from the top-soil to the parent material.

The second point is that in the semi-arid and humid zones of the Mediterranean regions, soils with no carbonate occur frequently on carbonate rocks; "terra rossa" or certain red Mediterranean soils on hard carbonate rocks, are well known examples of this. However, these soils are not included in the scope of this paper.

1.3. Vertical and Lateral Variations of the Calcareous Profiles

To understand the distribution and genesis of these calcareous soils, it is important to study the vertical and lateral variations of the Bca horizons and the correlations that exist between the different types of accumulation and those that exist between the Bca horizon and the A and C horizons.

1.3.1 In a complete Bca horizon the vertical transition between the different layers of accumulation is gradual. From the base of the soil, there is a gradual transition from a layer with soft concentrations and nodules to the nodular lime crusting, then to the crust and to the slab. Only the ribboned pellicule has a distinct limit.

1.3.2 In a catena of soils, in the lateral modification of the Bca horizon, lateral and progressive transitions between the different types of Bca can frequently be noted. There are progressive changes in a Bca with soft concentrations and nodules to non platy lime crusting, to platy lime crusting, and finally to the compact slab. In this catena, there is a progressive increase in the carbonate content and in the thickness of the Bca horizon, the increase in the carbonate content is more accentuated toward being more and more situated on the top of the Bca. This is one fairly frequently encountered example of lateral transition between non platy and platy lime crusting.

It can be concluded that the different types of Bca horizons are closely associated, vertically and horizontally and that they certainly result from the continuous influence of certain pedogenetic mechanisms. Only the ribboned pellicule is independent of these processes.

1.3.3 The correlations between the A and the Bca horizons and the transition between the two need to be considered. When the Bca is diffuse or has soft concentrations or nodules, the transition between the two horizons is progressive; there is a progressive increase in the calcium carbonate content although it is quite impossible to note definite limits on the profile and on the curve.

The transition between an A and a Bca horizon becomes more and more clearly marked laterally in a catena passing from a moderate differentiated profile towards a more differentiated one, that is towards a lime crusting. In the very well differentiated profiles, the limit between the A and the Bca horizon is always very clear and this limit always corresponds to a rapid and significant increase in the carbonate content.

Regarding the correlations between the carbonate content of the A and Bca horizons, it should be noted that there are no correlations; above a weak and thin Bca or above a very thick calcareous crust with a compact slab, the same A horizon can be found and it can be rich or poor in carbonate and either thin or thick.

These facts concerning the transitions between the two horizons, the very weak correlations between the carbonate contents of the two horizons and certain others demonstrate that the carbonate which accumulates in the Bca has a partly lateral origin, that there is in the soils an important lateral migration of the carbonate. This is confirmed when we study the correlations between the Bca and the C horizon; the transition between the two horizons is always progressive and all kinds of carbonate accumulations can develop in non calcareous and in non calcic parent material; however, the presence of a calcareous or a calcic parent material at the top of the slope is necessary to provide the Ca for the lateral migration.

1.4. Distribution of the Soils

Turning now to the principles governing the distribution in these lands of the different types of calcium carbonate profiles, there are several relevant factors.

1.4.1 An accentuation in the accumulation of carbonate is a function of time. For example, when studying the differentiation of the carbonate profile of soils situated on Quaternary alluvial terraces, it will be found that it increases with the rise from the young and low terraces to the high and old terraces. The following sequence will be found: diffuse accumulation, nodules, lime crusting, and a very hard and thick slab. But, in confirmation of

remarks made previously in this paper, the increase in the carbonate accumulation is not accompanied by a decarbonization of the A horizon. There is however a light decarbonization on recent terraces but this does not increase on the older ones.

1.4.2 In the distribution of soils along a slope of a certain age, the differentiation of the Bca increases as the slope descends. The thickness of the A horizon also increases. This is the result first of the lateral migration of the calcium in the soils and secondly of slight surface erosion.

1.4.3 When considering the decarbonization of the A horizon in relation to the parent material and as a result of the climate, two points should be borne in mind.

- (i) The decarbonization of the A horizon is more pronounced when the alteration of the parent material is slower or when it is more permeable and, obviously, when the parent material is poorer in carbonate. For example, the decarbonization of the A horizon is more pronounced in soils developed on hard calcareous rocks or on calcareous sandstones, than in soils developed on marls, which are impermeable and subject to rapid alteration and erosion. In such conditions total decarbonization of the A horizon is impossible in Mediterranean and arid countries.
- (ii) Passing from the arid to the humid climate, there is a slight augmentation of the decarbonization of the A horizon. This increase is more noticeable on hard or permeable calcareous parent materials, than on marl or alluvions.

1.4.4 The Bca horizon changes very little in relation to the climate. It is worth recording that in young soils, the Bca horizons are better differentiated in the subhumid than in the arid regions and that in old soils, the platy forms of the lime crusting are better developed in the arid and semi-arid countries than in the humid ones. This is because the hard and platy forms of the lime crusting result from consequential and rapid variations in the humidity of soils.

1.4.5 Concerning the relation between the Bca horizon and the parent material, it is important to remember that, because of lateral migration in the soils, calcareous soils can be found on non calcareous rocks and also on non calcic rocks. Furthermore, it is interesting to note the influence of the texture of the parent material; hard nodules and hard forms of lime crusting are particularly favoured by coarse texture.

The foregoing remarks can be considered as a summary of the essential points concerning the morphology and distribution of calcareous soils in Mediterranean, arid and desert regions.

The calcium carbonate profile is, of course, not the only important feature of these calcareous soils. It is also necessary to study: the textural profile, the structural profile, the colours, the organic profile, the repartition of the iron in the soils, the characteristics of the base exchange complex and of the soil solution, the mineralogy of the clay, etc.

There is a great deal to be said on these subjects but it is beyond the scope of this paper. However, there are some brief facts about texture, structure and colour which should be mentioned.

Main types of Bca Horizon

| Nomenclature of the types of distribution and individualisation of the calcium carbonate in the Bca horizons | | Definition and summary description | Clarity of the limits of the horizons | Thickness of the horizons | Colour | Hardness of the horizons | CaCO ₃ content of the horizons | Remarks |
|--|--|--|---|--|---|---|--|--|
| <u>Diffuse distribution</u> | | Calcareous particles < 1 mm appearing distributed haphazardly in a horizon | <u>Bca horizons with a diffuse distribution with or without pseudo-mycelium</u> | | Generally paler than the horizons which enclose it | Weak | < 40 % | |
| <u>Pseudo-mycelium</u> | | Calcareous filaments emphasizing the porosity | Very diffused limits often invisible | About 10' cm | | | | |
| <u>Friable accumulations</u> | | Friable accumulations of CaCO ₃ dispersed in the horizons, their limits being diffused or clear; the forms and dimensions are variable | <u>Bca horizons with friable accumulations with or without nodules</u> | | Friable accumulations: white to cream Nodules: white to salmon according to the hardness. In accumulations and nodules also red or black stains. Between the accumulations and the nodules: brown or ruby | Weak to Medium | Horizons with friable accumulations: < 50% Horizons with accumulations and nodules: < 60% | Between the friable accumulations and nodules the distribution of the calcium carbonate is diffuse with or without pseudo-mycelium. The stalactite form of coating which overlies and clings to pebbles can resemble nodules. |
| <u>Nodules</u> | | Granules : vol. < 1 cm ³ Nodules (s.s.) vol. = 1-100 cm ³ . Pebbles vol. > 100 cm ³ | Hard concentrations of CaCO ₃ dispersed in the horizon. The limits of these nodules are clear; the forms are variable - often spherical cylindrical or conical, the internal structure being varied. | Diffused limits | | | | |
| <u>Non-laminated encrustations</u> | | <u>Massive encrustations</u> Highly calcareous horizons, pale in colour with a massive or polyhedral structure | Usually clear limits at the top if there is no crust, diffuse if there is one. Diffuse limits at the base | <u>Bca horizons with non laminated encrustations</u> | | Medium to Strong | > 60% Progressive increase from the base to the top | Below non laminated encrustations. There are always horizons of friable accumulations with or without nodules |
| <u>Nodular encrustations</u> | | Highly calcareous horizons, pale in colour with a granular (nodular) and polyhedral structure | | About 10 cm to some metres: most frequently 30 to 200 cm | Rose, cream or white, more or less homogeneous, little black stains | | | |
| <u>Laminated encrustations</u> | | <u>Crusts</u> Highly calcareous horizons with superimposed and discontinuous (layers) of massive or nodular encrustation. Thickness of the layers increasing from the base toward the top: some mm to a few cm. | Limits: clear at the top, diffuse at the base, diffuse between the crust and the slab | <u>Bca horizons with laminated encrustations</u> | | Strong to very strong increasing from base to top | > 70% Increasing progressively from base to top | Below the crusts, there are nearly always non-laminated encrustations. The compact slabs exist only on top of these crusts. |
| <u>Compact slabs</u> | | Highly calcareous horizons of sheets with an indurated crust. Thickness of the layers: some cm to about 20 cm | | Some centimetres to more than a metre | Crust: white to whitey-cream, sometimes rose, black stains Slab: grey or salmon, whitish areas | | | |
| <u>Platy encrustations ribboned pellicule</u> | | Highly calcareous layers with a finely lamellar structure, overlying coating hard, calcareous or non calcareous surfaces | Clear limits | <u>Bca horizons with ribboned pellicule</u> | | Very strong | > 80% | These are situated on top of hardcrusts, laminated or not. They can also recover hard, slightly permeable rocks, are generally calcareous and surround pebbles |
| | | | Some millimetres to a few centimetres | White to salmon. Dark veins and streaks | | | | |

Discontinuous concentrations

Continuous concentrations - encrustations

1.5. Texture, Structure and Colour of the Soils

1.5.1. Concerning texture, it should be remembered that first, because of the presence of carbonates, textural analysis will always be difficult and should be interpreted with caution and secondly, that "B textural" are frequent in these soils, in all regions, humid or desert, but the limits are always diffuse. In soils where the superficial horizon is not calcareous, the "B textural" is above and in the upper part of the Bca, but in soils with calcareous superficial horizons, the Bt is generally less clayey and is situated at the same depth as the Bca horizon.

It seems that, in the majority of the calcareous soils, vertical leaching of the clay is of little importance, the accumulation of clay resulting mainly from alteration. However, if the vertical leaching is not too important, it is not the same for the lateral migration of the clay in the superficial horizon, and the result of this is that the first 10 or 20 centimetres of soil are frequently poor in clay. This phenomena is accentuated by cultivation which destroys organic matter and the structure.

1.5.2. From the colour and the structure of the superficial horizons, it is possible to distinguish three main types of soils.

The first type of soils are those with a dark epipedon, equivalent to the mollic epipedon. The value and the chroma of the humid soils are lower than 3.5; the structure of the horizon is well formed, crumbly and granular, very stable. These soils are frequent in the subhumid and semi-arid zones.

The second type of soils are those with a clear epipedon. The value and the chroma of the humid soil are between 3.5 and 4. The structure is more angular, less fine and less stable. These soils are frequent in semi-arid and arid zones.

The third type of soils are those with a very clear epipedon. The value and the chroma are superior to 4. The structure is weak, unstable and on the surface of the soil there is frequently a fine lamellar structure, forming a superficial crust. These soils are frequent in arid and desert countries.

These three types of soils, with dark, clear and very clear epipedon, can be calcareous or non calcareous in the A horizon and they can also have a Bca weakly, moderately or very well differentiated.

Given these three main characteristics; development of the Bca, content of the carbonate in the A horizon and colour and structure of this A horizon, the main types of calcareous soils in desert, arid and Mediterranean countries can be defined.

Two additional remarks should be made about the colour and the structure. The first concerns the red colour of the soils, and particularly the red colour of the superficial horizons; this colour is more accentuated when the carbonate content is weak, the climate is more humid and the parent material is red, which is very frequent.

The second remark concerns the structure of the Bt horizon, which depends on the content of clay, carbonate and organic matter.

1.6. Results of Human Action

In conclusion some remarks must be made on the result of man's action. In these regions when comparing some calcareous soils which have not been cultivated with those that have been cultivated or used for pasture, noticeable differences can be seen at once regarding degradation and decreased fertility of the soils. These differences are typified by :-

considerable diminution of the organic matter;

lightening of the surface colour and degradation of the surface structure with development of a surface crust;

recarbonization of the superficial horizons and lateral leaching of the clay in these superficial horizons; and

conditions highly susceptible to erosion from water and wind.

This degradation has had particularly important consequences and is probably irreversible in the very arid zones. Remaining portions of the natural original vegetation of these zones bear witness that past climatic conditions were more humid than in present times. The equilibrium was delicate and the destruction by man and his domestic animals of the vegetation definitely destroyed this delicate ecological balance.

III.2.

DISTRIBUTION OF CALCAREOUS SOILS IN THE NEAR EAST REGION,
THEIR RECLAMATION AND LAND USE MEASURES AND ACHIEVEMENTS

by

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SUMMARY

By virtue of the predominantly semi-arid and arid climate and sedimentary formations that prevail in the majority of the countries in the Near East Region, calcareous soils occur extensively. The following orders have been identified: Calcic xerosols and yermosols, Gypsic xerosols and yermosols, Lithic Cambisols, xerosols and yermosols, Fluvisols, Regosols, Chronic and Haplic Vertisols. Relative progress has been achieved in the investigation, reclamation and utilization of calcareous soils in several countries of the region. To realise effective solutions to the field problems of calcareous soils, it is necessary that a concerted cooperative applied research programme be adopted by the countries of the region. In this programme stress should be directed toward determining soil classification criteria that identify the varying qualities and levels of land and water use potentials.

The discussion emphasised the importance of realizing a consensus by the Seminar on the definition of calcareous soils in terms of their interpretive qualities for land and water use.

2.1. Introduction

Calcareous sediments are a prominent feature of terrains in the Near East Region. Their stratigraphic forms and lithologic constitution can be traced to the prevailing climatic, hydro and biologic environments of the past geologic periods and in particular, the Quaternary and Holocene.

Calcareous soils whose parent material is the calcareous sediments, occur extensively in the Near East Region. The characteristics these soils acquire are mainly determined by the climate, parent material, topography and the hydrologic history of the terrain.

The calcareous soils, inspite of their extensive occurrence in all the countries of the Near East Region, their recognition as an intrinsic group of soils has been overshadowed by the other soil quality characteristics with which calcareous soils are closely associated. Saline, saline-alkali (sodic), hydromorphic, sandy, dryland, eroded, etc. soils are a few prominent examples for qualifying this point. Therefore, it is necessary to define calcareous soils in the following context:

"Calcareous soils are those soils with high calcium carbonate content whose physical problems of land and water use for crop production are primarily dominated by the high content of CaCO₃, especially the active fraction with high specific surface area".

2.2. Distribution of Calcareous Soils in the Near East Region

2.2.1 Kinds of calcareous soils and their general regional distribution

The calcareous soils have many different morphological forms. On the basis of the profile characteristics, the following main kinds are important:

- (1) Soils with a calcic horizon; Calciorthiss (USDA); Calcic Xerosols and Calcic Yermosols (FAO/Unesco).

These soils have a strong, developed horizon of lime accumulation in the sub-soil. The lime is concentrated in the form of concretions or in powdery form. The depth to the horizon usually varies and it is very important in land use. Shallow soils over calcic horizon are damaged by deep cultivation. Developed on Pleistocene alluvial deposits, these soils are quite extensive in Syria, Jordan, Iraq, Iran and Egypt in addition to some areas in other countries.

- (2) Soils with petrocalcic horizons; Durorthiss (USDA); Calcic Xerosols and Calcic Yermosols (FAO/Unesco).

These soils are like the ones with calcic horizon but the petrocalcic horizon has cemented lime hard pan and they are thus much worse. These soils cover quite extensive areas in southern Saudi Arabia as well as in northern Syria. In Iran and other countries they occupy small areas.

- (3) Soils with Gypsic and petrogypsic horizons; Calciorthiss (USDA); Gypsic Xerosols and Gypsic Yermosols (FAO/Unesco).

These are calcareous soils with a horizon of gypsum accumulation in the subsoil. The depth to the gypsum horizon determines the land use. These soils are usually not suitable for irrigation. They are very extensive in northern Iraq and eastern Syria.

- (4) Shallow soils over limestone or marl; Lithic Camborthids and Lithic Haploorthids (USDA); Lithic Cambisols and Lithic Xerosols and Lithic Yermosols (FAO/Unesco).

Such soils have a shallow root zone underlain by partially weathered rock and then the unweathered rock. Only shallow rooted crops and those crops that can tolerate the lime in the partially weathered rock zone can be grown. These soils occur extensively in southern Lebanon, western Egypt, Iran, Afghanistan, Pakistan and most of the other countries. They occupy steep slopes and have a serious problem of erosion.

- (5) Strongly calcareous soils formed in alluvium or loess but without calcic horizon;
Camberthids, Xerorthents and Torriorthents (USDA); Yermosols, Xerosols, Fluvisols and Regosols (FAO/Unesco).

These soils have more than 15 percent calcium carbonate mostly as silt size fraction. As there is no strong zone of lime accumulation, the root zone is quite deep. Such soils have either no profile development or only a weak structural B horizon. Occurring in the arid alluvial plains and the arid mountain valleys, these soils are very extensive, especially in Iraq, central Saudi Arabia, Yemen, Iran, Pakistan, and Afghanistan. Many parts of these soils are strongly saline or saline-alkali as well, for example the soils of the Mesopotamian plain.

- (6) Slightly or moderately calcareous soils with a weakly developed B horizon;
Camberthids (USDA); Xerosols (FAO/Unesco).

These soils occur in semi-arid climate usually on Pleistocene alluvial deposits or loess deposits. They have a fairly good structure and a fair amount of organic matter in the subsoil. They present the least problems amongst the calcareous soils. These soils occur in the semi-arid parts of Jordan, Lebanon, Syria, Iraq, Iran, Pakistan, Yemen and possibly other countries.

- (7) Calcareous very clayey soils; Xererts and Usterts (USDA); Chronic and Haplic Vertisols (FAO/Unesco).

These soils have a very high content of expanding type clays (montmorillonite). Their main problems are tillage and lack of internal drainage. Problems connected with lime are minor, although important for some crops. Such soils are extensive in Sudan but occur in small areas in Lebanon, Syria, Iraq and Pakistan.

2.2.2 Calcareous soils of Pakistan

The climate of Pakistan except for the narrow belt in the North is arid to semi-arid. Its aridity is on account of the low rainfall that falls in high intensity rainstorms associated with a high evapotranspiration rate. Varying levels of calcareous soil conditions prevail throughout its terrain excepting the northern narrow belt region. (SF/PAK 6 Report) The general soil descriptions of the prevailing calcareous soils are as follows:

Indus Basin

- (1) Calcareous soils with weak structure of semi-arid and arid zones where the CaCO_3 content range is 6 to 10 percent in lime nodule form from 90 to 120 cm depth. pH is 8.0 to 8.3. Haplic Yermosols.
- (2) Stratified alluvial soils with moderate calcareous conditions 8 to 10 percent CaCO_3 . pH ranges from 8.1 to 8.4. Calcaric Fluvisols.
- (3) Saline soils of the flood plains with moderate calcareous condition. pH is 8.0 to 8.4. Solonchaks.
- (4) Calcareous loess soils, strongly calcareous. Regosols, Cambisols and Yermosols.
- (5) Saline stratified soils of the Indus Delta moderately calcareous. Solonchaks.

Mountains and Deserts: The main rocks are limestones and calcareous shales and sand stones of Tertiary age.

- (1) Very shallow residual soils of the mountains - very shallow over rock mainly limestone, calcareous shale and sandstones. Calcaric Lithosols.
- (2) Strongly calcareous soils of mountain valleys - silt loam and strongly calcareous - the fine soil material and gravel are calcareous. Yermosols, Xerosols, Fluvisols and Regosols.
- (3) Very strongly saline soils of playas in western mountain areas - soil material calcareous and stratified. Takyric Solonchaks.
- (4) Soils of the sandy desert - the ridges have massive sands that are moderately or strongly calcareous. Regosols.

2.2.3 Calcareous soils of Iran

Seven geologic structural units in sequence characterize the terrains of Iran from the south-west to the north-east. These are: (a) Khuzistan Plain; (b) Antochthonous Folded Zone of the Zagros System; (c) Thrust Folded Zone of the Zagros System; (d) Central Plateau; (e) Elburs range; (f) The Kopet-Dagh or Turkoman Khurasan range; (g) Caspian Littoral. Limestone formations within these geologic structural units are common. Consequently, the soils which are formed contain varying levels of CaCO_3 contents. The main soil associations that were mapped by Dewan and Famouri (1964) are: (1) Soils of the plains and valleys; (2) Soils of the plateau; (3) Soils of the Caspian piedmont; (4) Soils of the dissected slopes and mountains. Two thirds of Iran is arid with Calcic Yermosols and strongly calcareous Haplic Yermosols and also Calcic Xerosols.

Calcareous soil conditions characterize the following soil groups within the soils of the plains, soils of the plateau and soils of the dissected slopes and mountains: Alluvial soils and their sub-associations; Grey and Red Desert soils; Sierozem soils; Brown soils; Chestnut soils; Desert soils and their sub-associations; Calcareous Lithosols and Regosols.

2.2.4 Calcareous soils of Iraq

The chains of mountains Tauros and Zagros that separate Iraq from Turkey and Iran respectively have predominantly calcareous rocks, mainly limestone. The soils of the old fluviatile terraces, floodplains, deltas and marsh estuary, as well as those of the eastern and fan Mesopotamian Plains contain CaCO_3 within a range of 20 to 30 %.

(Buringh, 1960). In all these regions, the CaCO_3 soil constituent is associated with varying levels of saline and saline-alkali (sodic) soil conditions. According to Al Tai (1968) the crystal fabric is the dominant plasmic fabric in the soils of the Mesopotamian Plain, the main constituents of which are primary calcite and intercalcareous crystallites of clay, silt and sand uniformly distributed in the s. matrix. The following soil groups amongst many others, were identified by Al Tai (1968). Under the Entisols: Typic Chromo Xererts, Entic Chromo Xererts; under the Aridisols: Typic Calciorthiss, Mollie Calciorthiss, Lithic Calciorthiss and Petrocalcic Paleargids.

In his study on the lime (CaCO_3) content of the Lower Mesopotamian Plain Soils in relation to the water analysis of the Euphrates and Tigris rivers, Delver (1960) noted that whereas the range of lime content varied between 20 to 30% in the floodplain zone, the range in north Iraq was from 40 to 70% and that a high fraction of this lime was in the sand fraction. Delver (1960) further noted that the Tigris river sediment contained more lime on an average than the Euphrates river sediment and that the lime was more concentrated in the silt and clay fractions and not in the sand fraction. It is deduced from this finding that the rivers in their transporting action sediment the lime in the form of concretions with the sand in the higher lying areas of the rivers.

2.2.5 Calcareous soils of Jordan

In Jordan, Turonian and Eocene geologic formation series Ajlun and Balqa respectively are mainly composed of limestone, marls and basalt chalk. These geologic rock series prevail in important agricultural areas in east Jordan. The soils that form from the weathering of these rocks are mainly silty clay and clay calcareous soils. Even in the high rainfed areas, CaCO_3 content in soils ranges between 20 to 25%. In the dryland areas, lime content exceeds 50%. According to Moorman's Soil Survey Report and Soil Map (scale 1:106, FAO), the prevailing zonal soils in east Jordan are the Grey Desert, Yellow Mediterranean (Brown) and Red and Yellow Mediterranean (including Terra Rossa). They are predominantly calcareous; CaCO_3 content ranges from 30 to 50%. Calcareous soils also prevail in the azonal Grumosols, Rendzinas, Brown, Solonchak, Vertisols, Regosols and Lithosols.

2.2.6 Calcareous soils of Lebanon

The geologic origin of all the sedimentary rocks of Lebanon are calcareous. The parent material of the soils of Lebanon originates directly or indirectly from these sedimentary rocks. These soils vary in the form, content and pattern of distribution of the CaCO_3 constituent.

The Jurassic deposits - hard dolomitic rocks - form the base of Mount Lebanon and the Anti Lebanon mountain chain. Overlying the Jurassic are the Cretaceous sediments. These sediments cover the west of Mount Lebanon and south-west of the Anti Lebanon mountains. Marl and other limestone deposits overlie the centre west zone. In the south, Eocene hard and soft limestone deposits occur. The coast is formed from Miocene and Pliocene marl and clay sediments. In the Quaternary the water and wind transporting agencies were active thus forming the alluvial and colluvial sediments of the Beqaa plain and the sandy coastal plain.

The following soils have been identified and characterized:

Soils overlying calcareous rocks: Red soils (Terra Rossa) at an altitude of 1 450 to 1 850 m highly decalcified (i.e. eluviated) clay 20-40%, CaCO_3 content 0-6%, pH 6.7 to 7.3; Yellow mountain soils less decalcified, CaCO_3 content 3-10%, pH 6.4 to 7; Brown soils: Clay 30-75%, CaCO_3 4-10%, pH 7 to 7.6.

Soils overlying marl: Red, yellow, black and grey, light grey and white Rendzinas, clay 5-25%, CaCO_3 range of 13 to 80% and pH 7 to 7.6.

Soils overlying sandy and greyish parent material: Sandy coastal soils, CaCO_3 6-12% (free of concretions) or 40-60% (concretions present) sand 70-98% and pH 7.4 to 7.8.

Soils overlying basalt: Clay 22-50%, CaCO_3 1-5% and pH 6.4 to 7.3 north Akkar and central south Beqaa.

Intergrade soils: Formed from a heterogenic mixture of colluviated material, sand, clay, marl, geologically old CaCO_3 and basalt. These soils vary in their stage of pedogenesis and characteristics.

Black or grey soils: The parent material of these soils is the colluviated material from which marl originates. They are hydromorphic - clay 30-35% (Akkar) or 4-10% (Beqaa), CaCO_3 varies from 3.5 to 87% and pH 7.2 to 8.

Steppe sub-desertic soils: Light chestnut soils, clay 16-30% CaCO_3 15-30% and pH 7.4 to 7.6. CaCO_3 may form a hardpan at the surface.

Yellow sub-desertic soils: North Beqaa and Anti Lebanon. Average annual rainfall less than 300 mm. Clay 4-11%, fine sand 35-65%, CaCO_3 30-45% and pH more than 7.4.

Soils overlying alluvium: No pedogenesis and variable in character according to local conditions.

2.2.7 Calcareous soils of central Sudan

The CaCO_3 content is the most significant constituent of the Vertisols of central Sudan where the Gezira and other major agricultural projects are located. (Daursink, 1971) CaCO_3 and not MgCO_3 predominates in these strongly calcareous central Sudan alluvial soils. Non-calcareous soils, in general, occur in areas where the average annual rainfall is 750 mm and above, i.e. southward. A high degree of positive correlation exists between both the CaO and CaCO_3 which may constitute 5 percent of the mineral soil composition supplied by the silt textural fraction.

The phenomenon that the CaCO_3 is incorporated with the silt size fraction in the Blue Nile and Nile throughout central Sudan may be attributed to the fact that the salt in the water of these rivers is mainly CaCO_3 which, by evaporation, is precipitated in the silt fraction of the sedimented silt.

A wide range of CaCO_3 content usually exists in the older alluvial terraces reaching to 51 percent but lower in the recent alluvial terraces. Here, the CaCO_3 has been observed in four authigenic forms: (1) few shell fragments in the top 50 cm; (2) few to frequent small to large hard black to grey nodules decreasing to the 1m depth; (3) few to frequent small to large soft powdery to yellow or brownish irregular concretions to 1 or 2 m depth; (4) few to dominant specks, dendrites, streaks, aggregates masses in soil particles in various horizons.

2.2.8 Calcareous soils of the Arab Republic of Egypt

The main soils of the Nile Valley and the Delta of the Arab Republic of Egypt are Anthropic Gleysols and Anthropic Entric Fluvisols (Elgabaly et al. 1969). The range of CaCO_3 content in the alluvial soils of the Nile Valley and Delta varies from 1 to 3 percent. The main soils with medium to high CaCO_3 content (3 to 30 percent) are those that border the fringe zone of the Nile Valley. Beyond the fringe zone of the Nile Valley and Delta eastwards and westwards the CaCO_3 content in soils increase to a range of 30 to 80 percent and higher. In these eastern and western desert zones, Elgabaly et al. classified these calcareous soils as follows:

Limestone Lithic Ermolithosols - the soil mapping unit for north and central parts of the Western Desert; Limestone Lithic Ermolithosols and Takyric Solonchaks for the Tertiary limestone plateaux near Siwa and Qattara Depression; Limestone Lithic Ermolithosols, Takyric Solonchaks and Lithosols for the geomorphologic transition between the Eastern and Western Deserts; Gravelly Ermolithosols for the Upper Terraces of the Nile and Dry Wadis; Argillic Ermolithosols for the Kharga and Dakhla Oases; Entric Regosols for the Middle Terraces of the Nile Valley and the Sinai terrains; Takyric Solonchaks and Dynamic Ergosols for the Farafra Oases; Marshy Solonchaks and Ochric Solonchaks for North Sinai to Lake Mariut; Marshy Solonchaks, Humic Solonchaks and Solonetz for the partly reclaimed North Delta zone; Salipet Regosols and Ochric Solonchaks for the North Depression of Siwa, Qattara and Wadi el Natrun. Salipetrosols, Ochric Solonchaks and Dynamic Ergosols for the fringe of Siwa and Qattara Depressions; Ermosols for the North West Coastal Region; Dynamic Ergosols for the plateau areas and depressions; Semistatic Calcic Ergosols for the northern sea coast of Abou Kir Bay.

2.3. Investigations on the Reclamation and Land Use of Calcareous Soils in the Arab Republic of Egypt and Lebanon

Relative progress has been realised in the investigations on the reclamation and utilization of calcareous soils in a few countries of the Near East Region and in particular in the Arab Republic of Egypt and Lebanon.

2.3.1 Arab Republic of Egypt

In the Arab Republic of Egypt, the calcareous soil areas that are being reclaimed as a result of the construction of the High Dam are estimated at 300 000 feddans (1 feddan= 1.05 acres) most of which lie west of the Nile Delta where the mean annual rainfall is 110 mm. The CaCO_3 content of the soils in this area is 20 to 45 percent, the origin of which is the sedimentary parent material. The CaCO_3 distribution in the soil profile is either uniform or localized caliche layers at varying depths from the surface.

The main reclamation and land utilization problems of these areas are:

- (1) Crusting of the surface.
- (2) Cemented condition of the subsoil layers.
- (3) Low availability of phosphorus.
- (4) Problems of potassium and magnesium nutrition as a result of the nutritional imbalance between these elements and calcium.
- (5) Problems of micronutrient availability.
- (6) Problems of water availability.

The main results of field experiments on the problems of highly calcareous soils were the following:

- a) Seeding to corn immediately following irrigation and at the lowermost third segment of the furrow.
- b) The effects of the levels of apparent density followed by soil moisture level, texture and CaCO_3 content were the factors in descending order of their effect upon reducing seedling emergence. Silt was the textural fraction with the highest effect in inducing surface crusting.

ments and timing of irrigation application of most of the cultivated crops in the Beqaa and Coastal zone, and on assessment of sprinkler and drip irrigations in citrus orchards in particular.

(2) The Lebaa Agricultural Experiment Station (Litani Project area) is experimenting with vegetable crops grown on highly calcareous soils under rainfed and irrigated agriculture. The highly calcareous Maghdonke series on the terraced area has a silty clay texture, montmorillonite clay, 53 percent CaCO_3 and 22 percent active CaCO_3 . The Kfar Falouse series on the low-lying area is silty clay loam with less montmorillonite mixed with kaolinite. The total CaCO_3 is 84% and the active CaCO_3 is 38%. Crust formation is a common feature of this series. The crops that tolerate to varying degrees the calcareous soil conditions are: vegetable crops (some), grapes, stone fruits, lequat (Akkedunya), peaches, plums, almonds, apricot, pomegranate, quince, mulberry, forage crops, legumes and grasses. Deep sub-soiling coupled with legume grass mixtures and organic manure application are considered the soil management improving practices.

(3) The Tyr Agricultural Experiment station's main activities are related to citrus production and crop water requirements.

(4) In Farar Research Station, plant nutrition department, research work in the laboratory is focused on plant nutrition and physiology and chemistry of calcareous soils. The mineralogy of the clay constituent in forty-one soil series, located in the main agricultural zones, has been identified. The fertility status and fertilization requirements could be assessed on the basis of the clay mineralogy identification. The chemical characteristics calcareous soils in relation to lime induced chlorosis are being investigated. The effect of the textural conditions of lime upon soil fertility is also being studied.

(5) The American University of Beirut is conducting research on the fertility of calcareous soils and plant nutrition.

2.4. Achievements

The pressure of increased population combined with the scarcity of the irrigated zone of the Nile river valley and delta prompted the Government of the Arab Republic of Egypt to expand the cultivated terrain to selected areas of the fringe and desert plateau zones adjacent to the Nile river valley and delta zone. This major decision in the history of land and water development of the Arab Republic of Egypt was taken when the High Dam Project was under construction. A total of 770 thousand feddans of calcareous soil areas are in the process of being reclaimed, improved and managed. This area is planned to be expanded to cover a total of 2 million 637 thousand feddans as soon as the 9 milliard cubic meters of more water become available to the ARE from the High Dam Project. The areas that have been reclaimed are estimated at 600 000 feddans.

In Lebanon land and water development activities have been carried out in highly calcareous soil areas. The Northern Region, Akkar Plain mainly, was subject to an SF/FAO Pilot Hydro-Agricultural Development Project. The Green Plan Organization operates in providing services to farmers for establishing terraced cultivated farms afforestation and soil and water conservation practices in the highly calcareous soils of the mountains and plains and coastal plain areas of Lebanon. Since its establishment in the mid 1960's a total of more than 8 000 hectares areas have been developed.

Several similar examples can be cited in the other countries of the Near East Region where calcareous or partially calcareous soil areas have been or are being currently developed. In Iraq a number of land reclamation and improvement irrigation

- c) Organic manure application proved useful.
- d) An interaction effect between nitrogen and potassium fertilization of wheat and barley was significant.
- e) Organic manure application and micronutrient spraying of fruit trees corrected the chlorosis condition due to iron deficiency.
- f) 15 to 30 pounds per feddan application of ferrous sulphate, zinc sulphate and manganese sulphate to soils or by spraying at the rate of 3 lb iron per feddan, resulted in highest yield of corn and barley.
- g) Barley tolerates higher levels of boron in calcareous soils than does corn.
- h) To induce the water infiltration through calcareous hardpan subsoil layers, heavy irrigation application at short intervals proved successful.
- i) Subsoiling at 70 cm relieved the cemented hardpan layer.
- j) Prior to the transplanting of grape vines deep holes are made to break the hardpan layer. Areas with hardpans should be avoided to avert secondary salinization effects.
- k) Growing of alfalfa on calcareous soils with hardpan proved beneficial in relieving this condition.
- l) The cropping pattern suitable for the initial stage of land utilization of highly calcareous soils is the following:

| | |
|-------------------|--|
| One-third of area | Alfalfa |
| One-third of area | Berseem (<u>Trifolium alexandrium</u>) clover followed by maize |
| One-third of area | Small grains followed by cowpeas (lubia) for forage |

At the termination of the initial stage of land utilization of highly calcareous soils, the following cropping pattern is recommended:

| | |
|-------------------|---|
| One-third of area | Grape vines |
| One-third of area | Alfalfa |
| One-sixth of area | Small grains followed by maize for summer crop |
| One-sixth of area | Legumes in winter followed by summer vegetables. |

2.3.2 Lebanon

(1) The Tel Amara Agricultural Experiment Station is carrying out soil fertility field work on soils which are calcareous with varying levels of active CaCO_3 content. Research has been conducted on wheat nitrogen fertilization and potassium fertilization of sugarbeets. A number of basic investigations are being carried out on water require-

and drainage projects with a total of more than 100 000 hectares of partially calcareous soils are being developed. In the Syrian Arab Republic the Euphrates Project area - a basically calcareous soil area - is in the process of being developed for irrigation and drainage. In Jordan the SF/FAO Sandstone Aquifer Project identified rich groundwater resources suitable for irrigated land use of predominantly calcareous soil terrains.

2.5. Conclusions

1. The occurrences of calcareous soils is widespread in all the countries of the Near East Region.
2. Relatively good progress has been made in the reclamation and utilization of calcareous soils carried out in the Arab Republic of Egypt and Lebanon.
3. To realize effective solutions to the field problems of calcareous soils it is necessary that a concerted cooperative approach be taken by the countries of the Near East Region along the following courses of action:
 - (a) Delineation through soil survey field operations the calcareous soil areas that are acutely afflicted with the problems of lime induced chlorosis. This field study is to be combined with a detailed characterization of the soils of these areas.
 - (b) Establishment of representative pilot experimental areas for the conduct of laboratory/greenhouse/field experimentation on:
 - (i) Multivariant single or double factor experiments;
 - (ii) Multivariant multifactor experiments.

The subject-matter of this programme of applied research and experimentation may be selected from the relevant facets of soil physics, soil chemistry, soil microbiology, soil fertility, clay mineralogy and plant nutrition. As an integral part of the latter approach, field experiments on the following factors are proposed: cultural practices; cropping pattern; irrigation and drainage practices, amendment application and fertilizer use.

- (c) Establishment of representative pilot development areas on land and water use of calcareous soils for which a cropping pattern of relevance to the local rural community be implemented. Account has to be taken in this respect to apply the pertinent reclamation, improvement and management practices for calcareous soils. Since these field operations have to be carried out on profitable agricultural production economic grounds, it is imperative to keep the input-output record on the field operations. This information has to be duly analysed and interpreted in terms of the criteria of economic profitability.
- (d) Collection, reviewing, analysing, and dissemination of the literature on relevant problems of calcareous soils published in the countries where progress has been achieved in this line of action.

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MORPHOLOGY, MECHANICAL COMPOSITION AND FORMATION
OF HIGHLY CALCAREOUS, LACUSTRINE SOILS IN TURKEY

by

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The Great Konya Basin is in the South of the Central Anatolian Plateau in Turkey. It is a depression without outlet to the sea. The central part of the basin is the floor of a former Pleistocene lake. This area has highly calcareous clayey sediments and is flat and level. The best drained parts of it were mapped as Steppe Marl Soils (Carbonatic Mallic Calciorthids) and are mainly cultivated with dry-farmed wheat. Small areas are irrigated.

The non-cultivated parts have a degraded steppe vegetation (Virgin Steppe Marls) and their structure is granular in the surface soil due to a high biologic activity. The subsoil of all Steppe Marls is very fine compound prismatic. The cultivated soils show a degradation of soil structure including a clearly compacted plough bottom. This degradation of soil structure is more pronounced if the soil is slightly saline-alkaline.

The profile of irrigated Steppe Marls has a severely degraded surface soil structure due to puddling but it is salt-free and subsoil structure is improved by biologic activity as a result of increased moisture.

The soil texture without removal of carbonates is mostly clay to silty clay and is slightly finer textured after carbonates have been removed. The carbonates (mainly calcium carbonate as calcite) occupy about an equal proportion of the clay, silt and sand fraction (with more than average in the fraction 2-8 cm). Clay minerals of the smectite group are commonest.

The carbonatic clayey parent material of the concerned Marl Soils is a sediment of about 60% mainly chemically precipitated calcite, debris from limestone and shells. The rest is a residue of non-calcareous clay minerals of residual and alluvial origin and sand sized mineral grains of alluvial or aeolian origin. This material is homogenized by organisms.

3.1. Introduction

The concerned soils are situated in the Great Konya Basin in the south of the Central Anatolian Plateau. The central part of this basin is the floor of a former Pleistocene lake. This area, called the Lacustrine Plain, has highly calcareous clayey sediments and is flat and level, except for ancient shorelines which form sandy ridges and beaches. Its soils have been studied in the summers of 1964-68 as part of the Konya Project, a research and training programme of the Department of Tropical Soil Science of the Agricultural University of Wageningen, the Netherlands (de Meester, Ed., 1970, de Meester, 1971).

The soils of the Lacustrine Plain were mostly formed in white, uniform carbonatic clay, but differ markedly in composition and morphology, because of past and present differences in hydrology, topography and vegetation. The climate at present is semi-arid with hot, dry summers and cold, moist winters. The annual precipitation is about 300 mm, mainly falling from November to April. Total evaporation exceeds precipitation by 1000 to 1500 mm. The frost-free season is about 165 days.

The soils of the Lacustrine Plain have been studied and mapped on a regional basis and divided into 3 main types: Steppe Marl Soils, Marsh Soils and Playa Marl Soils, respectively classified mainly as Calciorthids, Haplaquolls and Haplaquepts. As the two last mentioned types of Marl Soils are strongly salt affected and therefore, amongst other reasons, not so suitable for agriculture, this paper will concentrate on the Steppe Marl Soils. Steppe Marl Soils developed in the best drained parts of the plain. They are not or seldom liable to flooding.

3.2. Steppe Marl Soils

Though the profiles of Steppe Marl Soils have many common features, they differ because of use and degree of salinity. Four examples have been selected to demonstrate those differences: Profile C 3.1 (Fig. 1) of a dry, never cultivated soil, profile C 3.2 (Fig. 2) of a dry, cultivated soil, profile G 1.1 (Fig. 3) of an irrigated soil, and profile D 31 (Fig. 4) of a dry cultivated, slightly saline-alkali soil.

The surface soil is always light-olive-grey to greyish and olive-brown, with an organic carbon content of 0.5-1.7%. The subsoil is invariably pale-olive with clear or faint iron oxide mottles and no organic carbon at all. Very characteristic is the crumb-like structure of the surface soil, resulting from intense biologic activity.

The profiles from the dry cultivated sites (C 3.2 and D 3.1) show a very clear plough bottom (A_p2). The subsoil has a characteristic, fine prismatic structure consisting of very fine angular-blocky elements. As regards D 3.1 the ECE data indicate that the soil is slightly salt-affected between 0-50 cm and according to its Exchangeable Sodium Percentage (ESP > 15, pH about 8.3) saline-alkali below 50 cm.

For all soils the calcium carbonate equivalent ranges from 30 to 70%. The surface soil is often less calcareous than the subsoil, presumably because of leaching. In all profiles a calcic horizon occurs at about 50 cm; it represents secondary lime accumulation, as normal in soils of semi-arid regions. The often faint and brownish-yellow (10YR 6/8) rust mottles cannot be explained as a result of recent oxido-reduction because the substrata of both lacustrine plains are too dry and permeable, as shown in the moisture studies by Jansen (1970) and by permeability tests. Presumably the wide-spread yellow mottling has been formed during the last stage when the ancient lake was drying up by fluctuations in watertable near the surface. Thus the mottles are fossil.

The saline-alkali profile D 3.1 has clear coatings (cutans) in the subsurface horizon, resulting from migration of clay-humus compounds mobilized under the slightly alkali conditions presumably existing at the end of the dry season (Driessen, 1970). The first heavy rainshowers wash down some of the surface material, which settles on the peds in the subsurface layer.

The Steppe Marl Soils are irrigated here and there. G 1.1 is a profile from a field that was irrigated for some eight years. The data show that salts have been entirely removed to give a less prismatic subsoil. Due to puddling, however, the structure of the surface soil became subangular-blocky, thus deteriorating as compared with the original crumb-like structures of the nearby dry Steppe Marls, but the subsoil shows biological activity to a greater depth.

3.3. Mechanical Composition of Marl Soil

3.3.1. The analysis

The textural composition was studied, mainly to detect the origin of the carbonate fraction. The plasmic structure of the Marl Soils is mainly porphyroskelic with a fine or very fine crystic plasmic fabric (Fig. 5, terminology according to Brewer, 1964). Hard calcareous nodules and many shell fragments of all sizes are also present. The calcium carbonate equivalent ranges between 30 and 70%. A mechanical analysis of such soil material can be made of the whole soil or of the non-calcareous part only, but both present some difficulties mainly because dispersion may be hindered by organic matter and by calcareous cementation. If carbonates are not to be removed, mostly sodium pyrophosphate is used with good results. For Marl Soils I have found that simple stirring is as effective as 30 minutes in a 500 Watt ultrasonic generator, provided that sodium phosphate ($\text{Na}_2\text{P}_2\text{O}_3$) is added before or afterwards to keep the particles dispersed.

Gypsiferous samples have first to be washed with water of about 40°C to remove all calcium sulphate. The separation of the fractions by sieving or settling introduces a serious error, because carbonate grains and non-carbonate grains differ widely in shape and density: the sand fraction contains elongated shell fragments and rounded material, the clay and silt fractions contain carbonate crystals and clay micelles.

For mechanical analysis of the non-calcareous part of a soil, the carbonates are usually removed with cold diluted hydrochloric acid (Diagnosis, 1954). This treatment is insufficient to get rid of hard calcareous nodules, especially those of dolomite, but heating causes serious damage to the minerals (Ruellan, 1970).

All this leads inevitably to errors, so that a grain-size analysis of Marl Soils as such is difficult to interpret.

3.3.2. The grain-size distributions

The grain-size distribution in surface soil and subsoil was determined in some 50 Steppe Marl samples. Fig. 6 shows that the texture without removal of carbonate is mainly silty clay, which confirms the field assessment. The results also show that the texture in the surface of Steppe Marl Soils is slightly coarser than in the subsoil, which is explained by removal of the clay and silt fractions by wind.

The difference in texture of Marl Soils before and after removal of carbonates is given in Fig. 7. There was an average increase of about 25 percentage units in clay and a decrease of about 20 percentage units in silt and a decrease of 5 percentage units in the sand fraction.

The distribution of the carbonates over various grain-size fractions as determined by Atterberg's method is shown in more detail in Fig. 8: a rectangle represents a full sample. The percentages are expressed in calcium carbonate equivalent. The CaO/MgO relation has been added for each fraction for further information on the composition of the carbonates. The data show that the carbonate content in the clay fraction ranges from 12 to 43%, in the silt fraction from 26 to 70% (with more than average in the fraction 2-8 μ m) and in the sand fraction from 24 to 70%. The calcium carbonate equivalent of the soil is not the calculated average of all fractions, but has been determined on the full sample. Differences are within the experimental error.

The carbonate parts of the fractions may contain grains with smaller non-calcareous particles which should be added to the non-carbonate fractions. Table 1 shows, however, that the amounts vary considerably. Because the samples have been too small to obtain very accurate data, no corrections have been made in the totals per fraction.

Table 1. Non-carbonate components in Marl Soil fractions (profile E 3.1)

| Depth (cm) | Particle size in Marl Soil fraction μ m | Percentage particle-size distribution in non-carbonate fraction | | |
|------------|--|---|-------------|------------|
| | | 8-50 μ m | 2-8 μ m | <2 μ m |
| 0-5 | 2-8 | - | 58.5 | 41.5 |
| 105-170 | 2-8 | - | 86.1 | 13.9 |
| 0-5 | 16-50 | 100.0 | 0.0 | 0.0 |
| 105-170 | 16-50 | 84.0 | 2.7 | 13.3 |

3.3.3. Carbonate minerals

So far, the carbonate part of the Marl Soils, consisting of calcium and magnesium carbonates, has been expressed in calcium carbonate equivalent. The CaO/MgO relation in Fig. 8 shows that calcium carbonate predominates.

In addition, X-ray diffractograms have been made of 18 samples from six representative Marl Soils to obtain some semi-quantitative information on calcite, dolomite and aragonite in the carbonate minerals. Table 2 shows that almost all samples contain at least 85% calcite; the rest is dolomite. A few samples have less calcite and some aragonite, apparently from aragonite-bearing shells of *Dreissena*.

In the clay, silt and sand fractions separately, no carbonate minerals have been estimated. But differences may be expected, as morphological studies have revealed that the silt and sand fractions contain more shell fragments than the clay, whilst the clay and fine silt fractions consist of chemically precipitated carbonate crystals (see next paragraph).

3.3.3. Formation of Marl Soils

Several of the Guinier de Wolff X-ray diffractograms of Marl Soil samples show sharp lines for calcite and for dolomite, which indicate that these minerals occur in a well crystallized form. Together with observations on thin sections (Fig. 5) and

Table 2. Carbonate minerals in the carbonate part of Marl Soils derived from Guinier de Wolff diffractograms. The relation CaO/MgO is added for comparison.

| Sample Profile No | Depth (cm) | Calcite (%) | Dolomite (%) | Aragonite (%) | CaO/MgO | CaCO ₃ equiv. (%) |
|-------------------|------------|-------------|--------------|---------------|---------|------------------------------|
| 1 | A 11 | 20-32 | about 90 | about 10 | | 67.5 |
| 2 | | 40-58 | about 90 | about 10 | 6.5 | 74.7 |
| 3 | | 102-148 | 80-90 | 10-20 | 6.2 | 59.4 |
| 4 | E 31 | 0-5 | >95 | <5 | 10.8 | 45.9 |
| 5 | | 30-52 | >95 | <5 | 11.3 | 59.0 |
| 6 | | 105-170 | >95 | <5 | 12.4 | 44.6 |
| 7 | D 31 | 0-17 | >95 | <5 | 13.8 | 38.2 |
| 8 | | 21-45 | >95 | <5 | 10.0 | 48.5 |
| 9 | | 90-140 | >95 | <5 | 11.0 | 42.3 |
| 10 | G 1.3 | 0-25 | >95 | <5 | 12.9 | 59.0 |
| 11 | | 35-80 | >95 | <5 | 12.1 | 50.0 |
| 12 | | 80-120 | >95 | <5 | 10.5 | 75.8 |
| 13 | C 2.3 | 0-10 | >95 | <5 | 6.2 | 41.2 |
| 14 | | 55-80 | >95 | <5 | 10.0 | 37.8 |
| 15 | | 80-120 | about 95 | about 5 | 20.0 | 54.3 |
| 16 | E 1.3 | 0-5 | about 85 | about 10 | <5 | 7.8 |
| 17 | | 15-30 | about 75 | 10-20 | <5 | 4.6 |
| 18 | | 30-100 | about 75 | 10-20 | <5 | 57.7 |

with the electron scanning microscope, this strongly suggests that the carbonate clay fraction of Marl Soils is mainly formed by chemical precipitation, presumably in the shallow parts of the Ancient Konya Lake. A high pH, saline-alkali condition, and water rich in bicarbonates of Ca²⁺ and Mg²⁺ may promote this. Withdrawal of CO₂, partly during photosynthesis, eventually in combination with diurnal changes in water temperature, easily result in precipitation of calcium carbonates, and of dolomite which is less soluble (Skinner, 1963).

Carbonates are still precipitated on a small scale in the Lacustrine Plain, as observed in July 1967 in a shallow saline temporary lake where ooze of almost pure crystalline calcite formed almost 3 cm thick. The area soon dried up. In day-time the pH of the ooze was 8.8 (CO₃²⁻ and HCO₃⁻ were not measured).

Thick crusts of precipitated carbonates on waterplants were observed also in July 1967 in another small shallow saline pool. At 10.00 h the pH was about 10 in the middle and 7.5 near the shore; concentration of CO₃²⁻ and HCO₃⁻ were 2.75 and 6.38 meq/l, respectively. There was little change in pH at night, so that vegetation did not seem the direct cause. The extreme pH in both sites suggests the presence of sodium carbonate, which could certainly cause precipitation of calcium carbonate. X-ray diffractograms of these precipitates show mainly calcite, with less than 5% dolomite. The electron scanning micrograph shows typical carbonate crystals in ooze and crusts.

After drying up, the precipitated carbonate sediment was on both sites about 0.4 cm thick. Already in the muddy stage, numerous organisms had started working the material. A few weeks later, the precipitated crust had completely disappeared from the surface by the activity of organisms and by cracking after drying. The material was mixed with parts of the surface soil.

presumably Marl Soils in the Lacustrine Plain initially formed in this way.

In summary, it seems that the carbonate clay and fine silt fractions in the Marl Soils mainly originate from precipitation and that the non-carbonate clay component has been blown and washed in or has been formed in situ. The coarser carbonate fractions are crushed shell fragments, limestone debris from coastal erosion, and secondary aggregates. The coarser, non-calcareous components are carried in by rivers and wind. Finally the resulting calcareous soil material is homogenized by organisms.

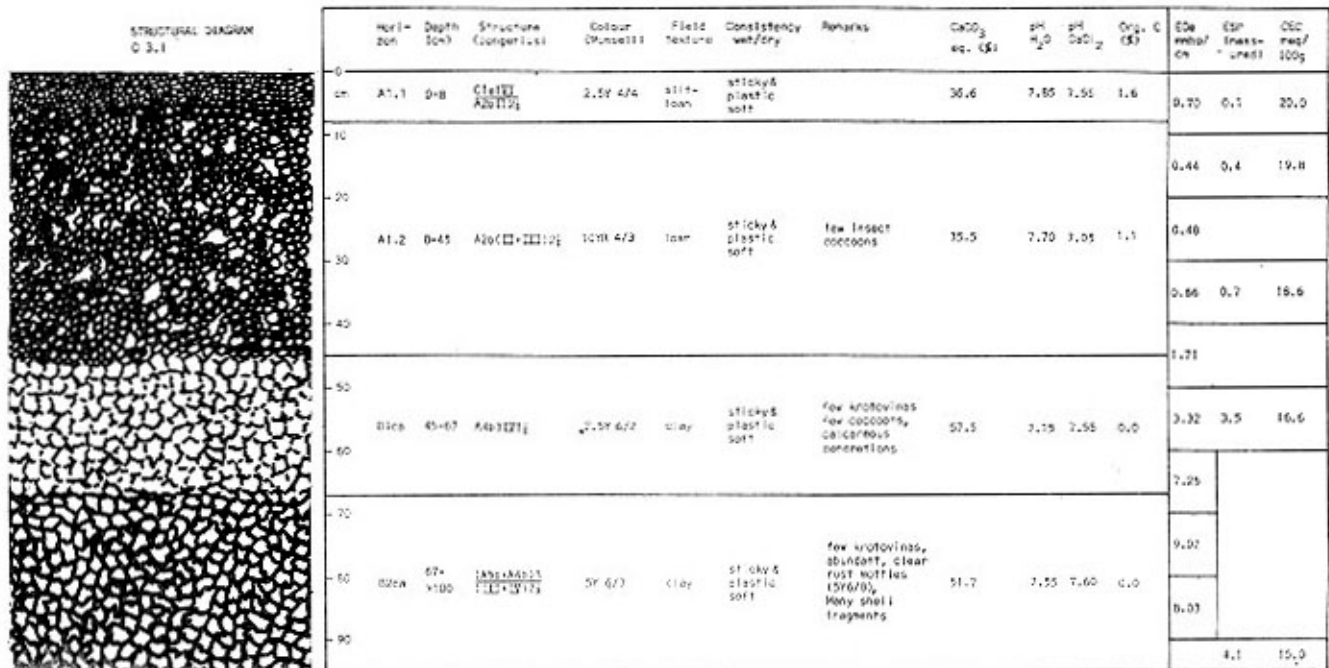
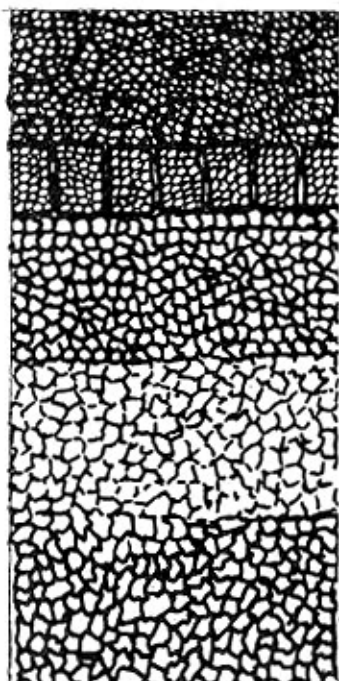


Fig. 1. Field description and analytical data of Profile C 3.1

diagnostic horizons : Ochric epipedon
Cambic horizon
Calcic horizon

classification (1967) : Fine carbonatic Mollic Calciorthid.

STRUCTURAL DIAGRAM
C 3.2



| Horizon | Depth (cm) | Structure (Jongerius) | Colour (Munsell) | Field texture | Consistency wet/dry | Remarks | CaCO ₃ eq. (%) | pH H ₂ O | pH CaCl ₂ | Org. C (%) | ECe mmho/cm | ESP (measured) | CEC meq/100 g |
|---------|------------|-----------------------|------------------|---------------|--|--|---------------------------|---------------------|----------------------|------------|-------------|----------------|---------------|
| | 0 | | | | | | | | | | | | |
| Ap1 | 0-20 | A6b1T11 A3a1T121 | 10YR 4/3 | silt-loam | sticky & plastic, soft | ploughed with clods | 31.4 | 8.20 | 7.50 | 1.23 | 0.96 | 0.5 | 20.3 |
| | | | | | | | | | | | 0.62 | 0.6 | 20.4 |
| Ap2 | 20-30 | B2.2T23 A3a2T121 | 10YR 4/3 | clay-loam | sticky & plastic, hard | few cocoons | 32.0 | 7.85 | 7.45 | 1.21 | 0.54 | 0.5 | 19.4 |
| | | | | | | | | | | | 0.35 | 0.9 | 19.6 |
| A1 | 30-50 | A4a1(T11+T2)1 | 10YR 4/3 | clay-loam | slightly sticky & slightly plastic, soft | few cocoons | 41.6 | 7.70 | 7.50 | 0.98 | 0.38 | | |
| | | | | | | | | | | | 1.16 | 2.7 | 18.0 |
| B1ca | 50-72 | (A4b+A5b)3 T211c | 5Y6/3 | silty clay | slightly sticky & slightly plastic, hard | many, clear medium calcareous concretions | 57.0 | 7.30 | 7.20 | 0.0 | 3.22 | | |
| | | | | | | | | | | | 3.08 | | |
| B2ca | 72-90 | (A4b+A5b)3 T211c | 5Y6/3 | silty clay | sticky & plastic, slightly hard | common, clear fine rust mottles, 12.5 Y 6/6, few shell fragments | 54.2 | 7.70 | 7.60 | 0.0 | | | |
| | | | | | | | | | | | 3.74 | 5.6 | 17.7 |

Fig. 2. Field description and analytical data of Profile C 3.2

diagnostic horizons : Ochric epipedon
Cambic horizon
Calcic horizon

classification (1967) : Fine carbonatic Mollic Calciorthid.

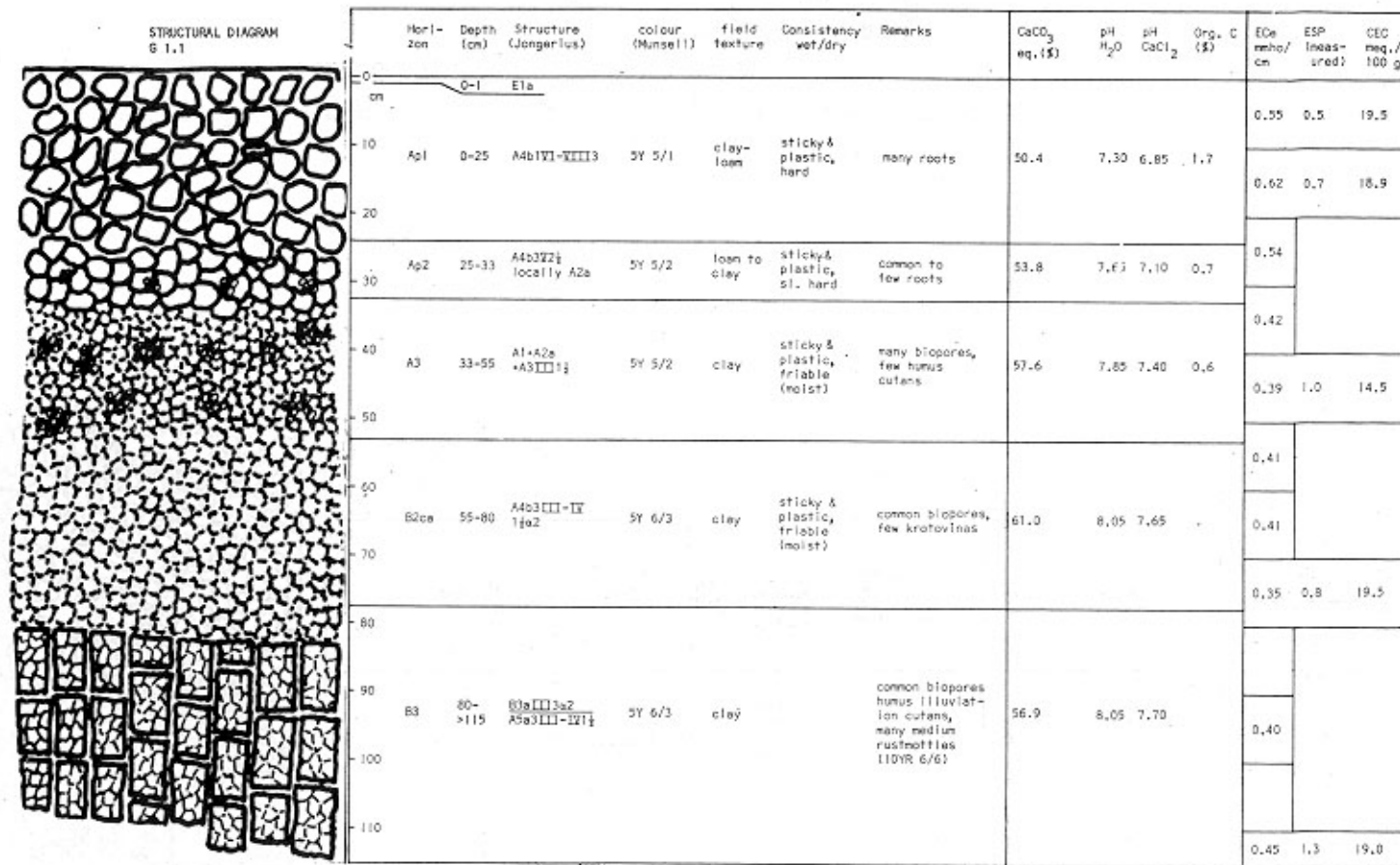


Fig. 3. Field description and analytical data of Profile G 1.1
 diagnostic horizons : Ochric epipedon
 Gambic horizon
 Calcic horizon
 classification (1967) : Fine carbonatic Mollic Calciorthid.

STRUCTURAL DIAGRAM
D 3.1



| Horiz- zon | Depth (cm) | Structure (Jongerluk) | Colour (Munsell) | Field texture | Consistency wet/dry | Remarks | CaCO ₃ eq. (%) | pH H ₂ O | Org. C (%) | ECe mho/cm | ESP (meas- ured) | Na meq/l | CEC meq/ 100g | Gyp- sum (%) |
|---------------|---------------|--------------------------------|---------------------|------------------|--|--|------------------------------|------------------------|---------------|---------------|------------------------|-------------|---------------------|--------------------|
| on | 0-10 | | | | | | | | | | | | | |
| Ap1 | 0-17 | A3aIII | 2Y 4.5/2* | clay- loam | sticky & plastic, soft | | 36.8 | 7.6 | 1.3 | 0.92 | 1.78 | 5.6 | 20.2 | 0.4 |
| Ap2 | 17-21 | C4b2E3 | 2.5Y 4.5/2 | clay- loam | hard | plough bottom | 46.2 | 7.7 | 1.1 | 0.98 | 5.04 | 7.3 | 18.8 | 0.4 |
| B21cb | 21-45 | B3a3III 3a2 A4a+A5.1S II 2½ | 5Y 6/3 | clay | sticky & plastic, slightly hard | rootprints & cutans | 59.1 | 8.1 | 1.5 | 1.50 | | 10.8 | | 0.5 |
| B22 | 45-90 | B4a3II 3a2 A5a3IV2ja2 | 5Y 6/3 | clay | sticky & plastic, slightly hard | rootprints cutans, many coarse rust mottles (10YR 6/8) | 60.4 | 8.4 | 0.2 | 2.60 | 30.6 | 22.0 | 15.0 | 0.7 |
| C1cs | 90- >140 | B3a3III 1 A4a3IV1½ | 5Y 6/3 | clay | sticky & plastic, slightly hard | abundant gypsum veins, few coarse rust mottles | 58.2 | 7.9 | 0.1 | 10.0 | 24.0 | 92.0 | 15.8 | 2.5 |

Fig. 4 Field description and analytical data of Profile D 3.1
 diagnostic horizons : Ochric epipedon
 Cambic horizon
 classification (1967) : Fine carbonatic Mollic Camborthid.

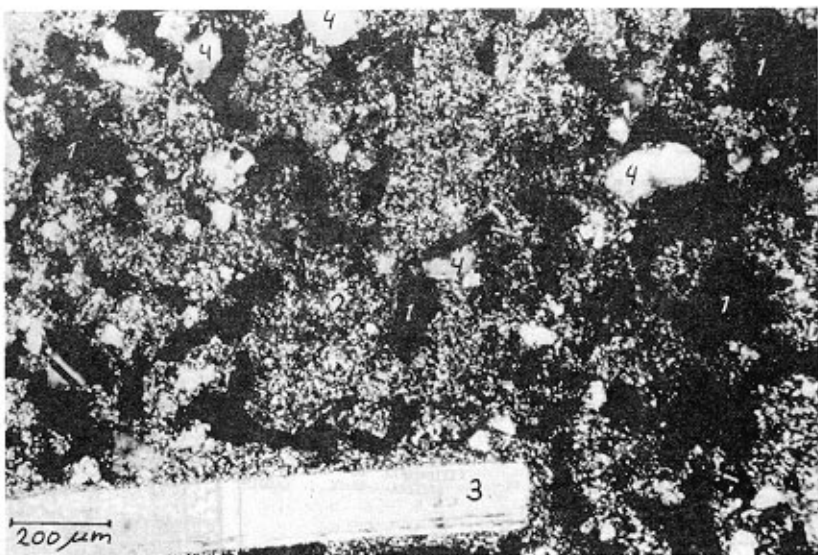


Fig. 5. Photomicrograph of a thin section from Profile C 3.1 (depth 20 cm). (1) vughs, (2) mixed loose cristic fabric, (3) shell fragment, (4) skeleton grains. Photographed with polarized light.

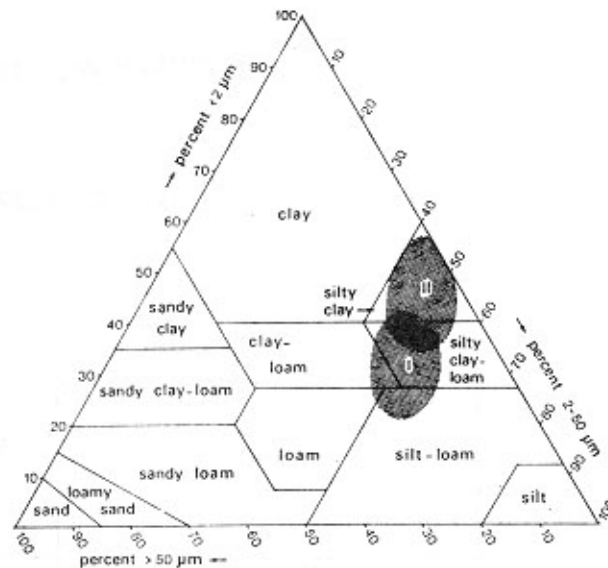


Fig. 6. Texture of surface soil (I) and subsoil (II) of Steppe Marl Soils (50 samples from 12 profiles).

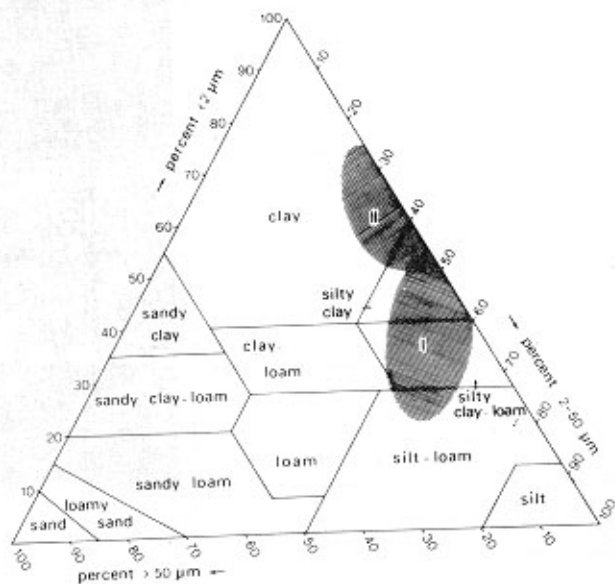


Fig. 7. Texture of Marl Soils before (I) and after (II) removal of carbonates (30 samples).

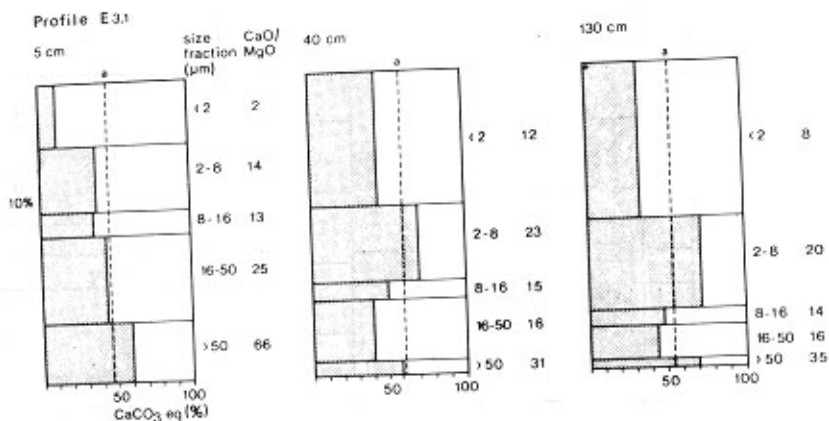


Fig. 8. Percentage of calcium carbonate equivalent per size fraction in 5 samples from a Steppe Marl Soil. Dotted line (a) is percentage calcium carbonate equivalent in whole sample.

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DISCUSSION

The discussion concerned terminology; "calcareous" is a general term for soil containing CaCO_3 , "carbonatic" is well defined and "Marl" is used in geology, soil science and the cement industry for soft lime; and about the pH in relation to the presence of sodium carbonate. It was accepted that small amounts of magnesium carbonate can raise the pH considerably, but presence of sodium carbonate will give the highest pH.

by

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SUMMARY

1. An evaluation of the P status of calcareous soils will probably lead to methods for making more quantitative fertilizer recommendations. Such methods will a) help correct P deficiencies where they exist, b) help recognize when a soil has an adequate supply of P, and c) help detect soils abundantly or amply supplied with P where continued fertilizer application may be wasteful economically. The excess supply of P in such soils may cause micronutrient deficiencies with Fe, Mn and Zn. If runoff or erosion occur from such soils into streams and lakes or reservoirs, pollution problems may arise from excessive algal growth.
2. The rate of P uptake by roots in a given soil was a linear function of the P concentration in the soil solution, or approximately linear in the range of concentrations from deficient to an adequate supply. However, when soils of various textures are compared at the same moisture suction (0.33 bar) the rate of P uptake was the same when the P concentration varied eightfold. The P supplying power of the various soils is explained by taking into consideration the differences between the soils in their diffusion coefficient of P and their capacity factors (the amount of P from the solid phase that will come into the soil solution for a unit change in concentration of P). An equation based on diffusion of P to roots takes into account these differences.
3. The equation may be used to calculate the concentration of P needed in soils varying in texture in order to obtain equal rates of P uptake by roots. Assumptions must be made for the concentration of P at the root surface, the root radius, and a rate of uptake that will assure an adequate supply of P for the crop. Applications of these methods have not been tested under field conditions.
4. Curves may be constructed to represent the reaction of fertilizer P with the soil after several wetting and drying cycles. These curves could be made for soils representing ranges in texture, CaCO₃ content, or other soil properties known to affect the reaction of fertilizer P with the soil. From the equation the concentration of P in the soil solution (or P potential expressed as $p(\text{H}_2\text{PO}_4 + \text{HPO}_4)$) required for equal rates of P

^{1/} Contribution from Agricultural Research Service, USDA, in cooperation with Colorado State University Experiment Station.

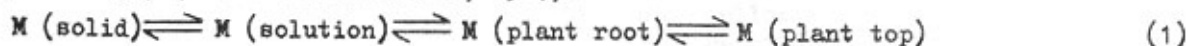
uptake may be calculated. From the reaction curves the amount of fertilizer P corresponding to the needed P concentration may be determined. The curve could also be constructed by using extractable P by the NaHCO_3 method (or other suitable methods). As a practical guide the level of NaHCO_3 extractable P for an adequate P supplying power to the roots will range from 15 ppm P on sandy soils to 20 ppm P on clay soils.

5. The soils which had an equal power to supply P to the roots contained approximately equal amounts of extractable P by the NaHCO_3 method. If the extractable P is expressed on a volume weight basis, the value for soils varying in texture tend to be more nearly the same when the soils have equal supplying power for P to plant roots.

4.1. Introduction

The phosphorus status of calcareous soils must be evaluated before quantitative fertilizer recommendations can be made. Usually, we rely upon soil tests, field trials including rates of P, previous history of cropping and fertilization, the crop to be grown, and the expected yield. These empirical approaches can be improved as we gain further knowledge and understanding of fundamental processes in soil-plant relationships. We must acquire more information about the nutrient supply characteristic of the soil and the environment and connect this knowledge to the nutrient supply required by the plant for optimum growth rates.

The process of nutrient supply can be divided into various steps as indicated in equation (1) (Fried and Broeshart, 1967):



where M is nutrient ion. Nutrient supply involves all these steps which occur simultaneously, but a steady-state approximation may be assumed. This assumption leads to the concept of a rate-limiting step; i.e., in equation (1) the slowest step determines the rate of the over-all process. The rate of reaction depends on the concentration of the reactants and the rate constant. A complete description of this process opens the way to possible regulation and control through management practices. The concepts illustrated by equation (1) will form a basis to examine the existing knowledge about ion uptake processes from calcareous soils, especially in relation to more efficient use of P fertilizer, and to indicate where new information is most needed.

The transfer of nutrients from soil to crop depicted by equation (1) emphasizes the interdependence of these processes. The soil may possess a certain potential to supply P to plant roots, but the actual amount supplied depends also on the properties of the root such as its length, radius, and its ability to lower the concentration of P at the root surface. This ability is not solely a function of the root but depends in part on the demands for P by the tops. As this concept applies to field conditions, the root density of a given plant becomes an important factor affecting nutrient uptake (Barley, 1970).

These relationships between root and soil are complex and the variables cannot be assigned numbers as yet for the entire growth period of a crop. A more practical approach is to use shorter periods of time for which numbers can be assigned in order to predict and measure the P supply to roots. The supply of P must be sufficient to maintain a given rate of growth and a given P content of the new growth. This rate of growth and P content can be set at different levels which depend on the crop, conditions of growth and the expected yield. Some trials with these objectives in mind have been reported on calcareous soils by applying diffusion theory to the relationships indicated in equation (1) (Olsen and Watanabe, 1970). These concepts will be examined further in this paper with special reference to calcareous soils.

4.2. Equation for Uptake of P

Some of the variables that control P uptake by plant roots can be combined in equations which describe the conditions existing when a nutrient diffuses to a root surface. A simplified initial and boundary condition will be assumed, i.e. a) initially the root surface has the concentration, $C = C_0$ when $t = 0$, and b) $C = C_r$ when $t > 0$, where C = concentration of P in the soil solution and t = time in seconds. Flux of P to a root was described by an equation under this boundary condition (Olsen, Kemper, and Jackson, 1962).

The integrated form with respect to time of the flux equation appears as equation (2).

$$Q = aB (C_o - C_r) (1.13T^{\frac{1}{2}} + .5T - .094T^{3/2} + .0625T^2) \quad (2)$$

where,

Q = amount of P absorbed in time, t, as g/cm² of root surface

a = root radius, cm

B = slope of line (b + θ) relating labile P in g/cm³ of soil to concentration, C, of P in the soil solution, g/cm³, and θ is the volumetric moisture content. B is a capacity factor.

C_o = initial concentration, g/cm³

C_r = concentration at the root surface, g/cm³

T = $D_p t / Ba^2$

D_p = diffusion coefficient of P, cm²/sec as defined previously (Olsen, Kemper, and Jackson, 1962)

Numerical values for the graphical solution of equation (2) have been given (Olsen and Watanabe, 1970, see Fig. 1). Numerical values for the graphical solution of the flux equation have been presented (Olsen and Kemper, 1968, see Fig. 2). Other boundary conditions may be assumed (Bouldin, 1961; Nye, 1968; Olsen and Kemper, 1968) but the relationships among the variables in equation (2) will suffice to illustrate the kinds of measurements needed. Practical applications of information gained from equation (2) will be illustrated in the discussion that follows. For example, data from equation (2) explain how roots absorb P at the same rate from soils of various textures which exhibit a 15-fold variation in the P concentration of the soil solution.

4.3. Capacity factor

This capacity factor, B, is an estimate of the amount of P from the solid phase that will enter the soil solution (thus becoming diffusible or available for uptake) for a unit change in P concentration of the soil solution. The capacity factor is important because the P concentration determined at the beginning of the growth period does not give sufficient information on the P supply to plants throughout the growth period. A method of measuring B that was applicable to all soils would be very difficult to find. Mainly, three methods have been tried: a) labile P measured by ³²P exchange, b) resin-extractable P, and c) the Q/I relationship ($\Delta Q / \Delta I$)L_o of Beckett and White (1964) or the differential phosphate potential buffering capacity (DPBC) of Jensen (1970, 1971). Jensen defined DPBC as the amount of P to be added or removed per gram of soil in order to obtain a certain alteration of the phosphate potential (0.5 pCa₂ + pH₄PO). Thus, the differential capacity is used to indicate that the buffering capacity depends on the phosphate potential.

The possibility exists that ³²P does not necessarily distinguish between available and non-available forms of P (Aslyng, 1964). Some fertilizer P changes into forms of such low solubility that these forms do not contribute to the available supply of P but such forms still undergo isotopic exchange with ³²P. When such reactions occur the ³²P method would overestimate labile P and predictions of Q in equation (2) would be too high. However, the use of equation (2) does not offer an accurate way to test the validity of a method to measure a capacity factor because of assumptions made in estimating a value of C_r. Therefore, other approaches should be taken to get an independent way of testing the validity of a given method to measure the capacity factor.

One approach has been to measure the diffusion coefficient (D_p) of P in a soil by two methods, a) one method requires an estimate of the capacity factor to get D_p (transient-state case) and b) the other method provides a measure of D_p that does not require an estimate of the capacity factor (steady-state case). Such comparisons have been made on two calcareous soils and the measurement of labile P by ^{32}P exchange (24 hours) appeared to give a valid estimate of the capacity factor because D_p was essentially the same by either method (Olsen, Kemper and van Schaik, 1965).

A comparison was made of the capacity factor measured by ^{32}P exchange and by anion resin-extractable P (Olsen and Watanabe, 1970). The values agreed closely on three calcareous soils. Studies of the Q/I relationships (Beckett and White, 1964) on these soils is underway.

The capacity factor increases as the clay content of soils rises as shown by data from each method. Labile P represents a surface-active fraction of a number of forms of solid phase P in soil including crystalline, colloidal, or adsorbed phases. The clay appears to promote a larger surface area of the reaction products between soil and fertilizer P (Beckett and White, 1964; Muljadi, Posner and Quirk, 1966; Jensen, 1970; Olsen and Flowerday, 1971).

The capacity factor was approximately constant in soils containing varying amounts of CaCO_3 derived from the same geologic origin, but it differed among soils with CaCO_3 from various origins. For example, a soil with CaCO_3 from Cretaceous Chalk had a capacity factor 2.7 times greater than another soil containing magnesian limestone (Talibudeen and Arambarri, 1964).

4.4. Intensity factor

The intensity factor, usually expressed as the concentration of P in the soil solution, is very important in the relationships shown in equation (2) because the difference ($C_o - C_r$) between the initial concentration and the concentration, C_r , at the root surface mainly controls the rate of P uptake by roots. The concentration, C_o , can be measured readily in water extracts or in 0.01 M CaCl_2 solution; however, the manner of expressing this concentration in a way which is most significant to plant roots is still not clear, especially for calcareous soils. In acid soils pH below 6 the concentration consists mainly of H_2PO_4^- ions and the intensity factor may be expressed in terms of activity, $a_{\text{H}_2\text{PO}_4^-}$, $p_{\text{H}_2\text{PO}_4^-}$, or $0.5 p_{\text{Ca}} + p_{\text{H}_2\text{PO}_4^-}$. In soils having a pH above 6 the presence of HPO_4^{2-} ions and a soluble calcium phosphate complex, CaHPO_4 , must be considered in expressing concentration activity of P.

The relative importance of HPO_4^{2-} in P uptake by plants has not been fully clarified. The plant response in soils above pH 6 appears to be correlated better with total P concentration (Aslyng, 1964; Wild, 1964).

Jensen (1970, 1971) presented data showing that a correction for the complex, CaHPO_4 , was necessary in measuring the DPBC of calcareous soils. He made this correction using an equation derived by Larsen (1965). With this correction the DPBC for three calcareous soils was the same in 0.01 M or 0.001 M CaCl_2 solutions whereas the DPBC differed for the uncorrected data.

Although this discussion points out problems and unanswered questions about how to measure and express C_o , there is much less information on how to measure or estimate C_r , the concentration at the root surface. These problems apply to acid and calcareous

soils. Hopefully, these problems will be solved because such knowledge is necessary to define the boundary conditions for using diffusion models to predict P supply to roots such as equation (2). Nye (1968) and Barley (1970) have indicated the nature of some of these problems and what experimental approaches may prove fruitful.

4.5. Diffusion coefficient

A third important factor in D_p equation (2) influencing the amount of P uptake by roots is the diffusion coefficient of P, D_p . This value varies with volumetric moisture content, θ , and factors for tortuosity of path length and negative adsorption (Olsen, Kemper and van Schaik, 1965). In several calcareous soils D_p ranged from 5.40×10^{-7} to 1.12×10^{-7} cm²/sec. Values were highest for clay soils and lowest for sandy loams (Olsen and Watanabe, 1970).

4.6. Nutrient supply

The nutrient supply of P in three calcareous soils was evaluated by using equation (2). Textural variations were highly correlated with the ability of these soils to supply P to plant roots. In these soils the roots absorbed P at the same rate when the P concentration, C_0 , varied fivefold (Olsen and Watanabe, 1970). Equation (2) based on diffusion of P adequately explained the differences in the P-supplying power of these soils varying in texture. Predicted values for uptake of P from equation (2) agreed closely with observed values. An average value for C_r was estimated from two boundary conditions, a) dq/dt is constant and b) C_r is constant when $t > 0$.

The P status of these soils is shown in Table 1. The initial level of C_0 was lowest for the clay soil but a significant increase in yield of barley in the greenhouse was observed with each soil. Addition of P as concentrated superphosphate (CSP) caused a larger increase in C_0 in the fine sandy loam than in the clay. This difference reflects the adsorptive capacities of the three soils. Relevant physical and chemical properties of these soils is shown in Table 2.

The diffusion coefficients and values of the capacity factor, B, by two methods are shown in Table 3. Values of D_p and B varied five-fold and ninefold, respectively, as texture differed.

The rate of P uptake by corn roots (24-hour absorption period) was linearly related to P concentration, C_0 , in each soil. From these the value of C_0 was estimated when the uptake was constant at 2×10^{-12} g/cm²/sec. These values of C_0 appear in column 2 of Table 4. A value of C_r for each soil was estimated using two boundary conditions as previously indicated. These values are shown in Table 4.

An average value of C_r from Table 4 was used in equation (2) to calculate Q and the comparison between predicted and observed values appear in Table 5. The observed value was 12 percent lower than the predicted value from equation (2). Better estimates of C_r will likely be possible as we learn more about the soil-root system.

Some practical applications can be made from using equation (2) and data required to solve a value of Q. If a value for Q can be estimated that will allow a plant to attain a high or adequate growth rate, then equation (2) may be used to determine the value of C_0 required to supply the estimated value of Q. Such calculations also require an estimate of C_r . A relationship between C_0 and fertilizer P added is also needed. By knowing the required C_0 from equation (2), the amount of fertilizer P can be determined which will give the necessary value of C_0 . Such data for three calcareous soils is

Table 1. Phosphorus status indicated by various measurements as related to level of fertilizer P (CSP).

| Soil | P Added (ppm) | P Concentration | | Labile P** (ppm) | Resin-P (ppm) |
|----------|---------------|----------------------|-------------------------------|------------------|---------------|
| | | Water extract* (ppm) | .01 M CaCl ₂ (ppm) | | |
| Pierre | 0 | .031 | .017 | 17.8 | 11.0 |
| | 17.5 | .058 | .031 | 24.3 | 18.0 |
| | 35 | .094 | .053 | 34.4 | 27.3 |
| Apishapa | 0 | .104 | .034 | 20.9 | 15.2 |
| | 17.5 | .209 | .092 | 29.8 | 24.3 |
| | 35 | .350 | .161 | 42.8 | 36.4 |
| Tripp | 0 | .220 | .045 | 10.3 | 6.3 |
| | 10 | .410 | .137 | 16.6 | 12.7 |
| | 20 | .800 | .305 | 22.9 | 18.1 |

* 40g soil/50 ml water.

** ³¹P that undergoes isotopic dilution with ³²P in 24 hours.

Table 2. Physical and chemical properties of soils

| Soil | pH* | Clay (%) | CaCO ₃ (%) | Bulk Density (g/cm ³) | H ₂ O at .33 bar (g/cm ³) |
|----------|------|----------|-----------------------|-----------------------------------|--|
| Pierre | 7.53 | 51.0 | 2.9 | 1.00 | .392 |
| Apishapa | 7.53 | 36.6 | 6.2 | 1.00 | .315 |
| Tripp | 7.20 | 15.0 | 0.2 | 1.32 | .177 |

* In .01 M CaCl₂.

Table 3. Diffusion coefficients and values of B in three soils.

| Soil | D_p cm ² /sec | B (Capacity Factor) | |
|----------|----------------------------|----------------------|--------------|
| | | From ³² P | From resin-P |
| Pierre | 5.40×10^{-7} | 267 | 255 |
| Apishapa | 3.23×10^{-7} | 87.5 | 86.2 |
| Tripp | 1.12×10^{-7} | 28.7 | 27.3 |

Table 4. Concentration of P (C_r) estimated at the root surface.

| Soil | C_o * g/ml soln. | C_r | | C_r/C_o | |
|----------|-----------------------|--|--------------------------------|-----------------------------|---------------------|
| | | Constant C_r condition g/ml soln. | Constant dq/dt g/ml soln. | Constant C_r condition | Constant dq/dt |
| Pierre | 0.96×10^{-7} | 0.57×10^{-7} | 0.47×10^{-7} | .59 | .49 |
| Apishapa | 1.96×10^{-7} | 1.08×10^{-7} | 0.88×10^{-7} | .55 | .45 |
| Tripp | 4.80×10^{-7} | 2.20×10^{-7} | 1.59×10^{-7} | .46 | .33 |

* Values from curves when uptake equals 2×10^{-12} g/cm²/sec.

Table 5. Comparison of observed and calculated rates of P uptake by corn roots in three soils

| Soil | C_r (Ave.) g/ml soln. | Q (Calculated)* g/cm ² /day | Q (Observed) g/cm ² /day |
|----------|----------------------------|---|--|
| Pierre | 0.52×10^{-7} | 1.94×10^{-7} | 1.73×10^{-7} |
| Apishapa | 0.98×10^{-7} | 1.93×10^{-7} | 1.73×10^{-7} |
| Tripp | 1.90×10^{-7} | 1.94×10^{-7} | 1.73×10^{-7} |

* Calculated from equation (2) and values of C_o shown in Table 4.

Table 6. Fertilizer P (as CSP) needed to supply $1 \mu\text{M}$ P per g of roots per day.*

| Soil | C_0 initial ppm | C_0 Needed ppm | $\text{P}(\text{H}_2\text{PO}_4 + \text{HPO}_4)$ | Fert. P ppm | $\text{NaHCO}_3\text{-P}$ at C_0 needed ppm |
|-----------------------------|----------------------|------------------------|--|-------------------|--|
| Pierre clay | .031 | .109 | 5.92 | 40.5 | 22.0 |
| Apishapa silty clay loam | .090 | .286 | 5.60 | 29.0 | 21.8 |
| Tripp fine sandy loam | .220 | .845 | 5.17 | 20.6 | 19.6 |

* Assumptions:

1. Corn roots: $a = .035$ cm, area = 57 cm^2 , 1 cm^3 roots = 1 g fresh weight.
2. $C_r/C_0 = 0.1$.

shown in Table 6. The value of C_0 needed to give an equal rate of P uptake on these soils varied eightfold. The fertilizer P (CSP) required to raise the P status to the needed level of C_0 varied twofold. Essentially the same estimate of fertilizer P needed was obtained by using the corresponding values of C_0 found in 0.01 M CaCl_2 extracts of these soils.

The phosphate potential, $p(\text{H}_2\text{PO}_4 + \text{HPO}_4)$, is shown in Table 6 for the values of C_0 in column 3. The potentials were calculated from the pH and P concentrations in 0.01 M CaCl_2 . A linear relation was observed between the P potentials and the clay content of these soils.

The validity of the assumptions indicated in Table 6 were tested by measuring the yield response of barley to CSP in the greenhouse for each soil. The rates of fertilizer P in table 6 were calculated based on a concept that these rates would raise the P status so that each soil had the same P-supplying power. If the estimated value of q is correct, then the percentage of the highest yield on each soil should fall near 100 for these calculated rates of CSP. At the rate of P as CSP shown in table 6, the percent of the maximum yield on each soil was 93.0, 97.4, and 96.5, and the P concentration in the plants was 0.213, 0.238, and 0.221 percent for the Pierre, Apishapa, and Tripp soils, respectively.

Aslyng (1964) suggested addition of fertilizer P to achieve a constant potential of P to maintain an adequate supply of P on various soils. He recommended a phosphate potential, $p(\text{H}_2\text{PO}_4 + \text{HPO}_4)$, of 5. The data in table 6 indicate that the potential of P varies in different soils when they have an equal supplying power of P to roots, i.e., from 5.17 to 5.92.

With reference to the potentials of known compounds, the solubility of P was calculated for the soils that received the amounts of P shown in table 6. On a solubility diagram these points plotted between the lines for hydroxyapatite (HA) and octocalcium phosphate (OCP), but they were nearer to the line of OCP. The phosphate potential of 5 recommended by Aslyng (1964) has a solubility point that lies very near to the OCP line.

If the solid phase P in a soil has a solubility corresponding to OCP, then the P-supplying power of such soil is likely to be unrelated to soil properties. This reasoning is based on the likely assumption that OCP dissolves rapidly enough to control the P concentration in solution (Lindsay and Moreno, 1960; Webber and Mattingly, 1970a). The data in table 6 indicate that sandy soils fertilized to an adequate level of P may reach a P potential near or equal to OCP. Clay and loam soils showed potentials less than OCP, although they supplied adequate amounts of P to plants. A Barnfield soil, with 31% clay, studied by Webber and Mattingly 1970b) had a very high P status (NaHCO_3 -soluble P was 67 ppm), but this soil in equilibrium with CaCO_3 was undersaturated with respect to OCP.

4.7. Research needs

Some areas of research that need attention are indicated below:

- (1) The role of P concentration in the soil solution, C_o , and at the root surface, C_r , needs evaluating in relation to the rate of P uptake by intact roots growing in soil. This means that information is needed on the proportionality coefficient relating rate of uptake to the P concentration. Such data are needed for different crops during critical growth periods, for various conditions of root growth, age, size, and density of roots. This information will lead to better measurements of the ability of soil to supply P to plants and improve the application of realistic boundary conditions to equations based on the diffusive supply of P to roots.
- (2) The uptake of P depends directly on the concentration of P in the soil solution but also on the quantity of P that will be released as the roots lower the concentration over a given range and on the diffusion coefficient of P. The nature and properties of the solid phase P contributing P to the soil solution needs further evaluation and definition. Under some conditions the P concentration may be controlled at a constant level at a given pH by compounds such as OCP or dicalcium phosphate, and the quantity that will be released equals the amount of the compound present. Under other conditions, the P concentration may be controlled by the labile P and its properties. In these cases, the P concentration usually varies linearly with the amount of labile P and the slope of the line is an important factor related to P uptake. Very little is known about the chemical nature and properties of labile P, although its measurement serves a useful purpose.

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SUMMARY

Calcareous soils tend to be low in organic matter and available nitrogen. The high pH level results in unavailability of phosphate and sometimes zinc and iron. Potential productivity is very high where adequate nutrients and water can be supplied. Many of the calcareous soils under cultivation are irrigated and the irrigation water may supply crops with all the amounts needed for such elements as magnesium, potassium, sulphate, chloride and boron depending on the salt content of the water.

Nitrogen needs to be provided in line with the amount likely to be removed in the crop. Excessive nitrogen may be detrimental to some crops (sugarbeets for example). Where restricted layers in the soil prevent leaching of nitrate it may accumulate to amounts in excess of 600 kilograms per hectare in the root zone of crops. The recently developed nitrate electrode gives a means of easily and quickly analysing soil samples for nitrate. Ammonium or urea nitrogen may be lost from the surface of calcareous soils unless they are incorporated immediately. Ammonium fixation on the clay complex may tie up a considerable amount of applied fertilizer on newly irrigated desert soils.

Soil testing (sodium bicarbonate extraction) is probably the most practical means of determining the need for phosphorus fertilizer. Excess applied phosphorus may result in deficiency of zinc or iron. For calcareous soils, it is important that at least 60 percent of the applied phosphorus be in a water soluble form. Applied phosphorus is only partially taken up by crops the first year but the residue will be mostly taken up over a period of years. Thus, once the available soil phosphorus has been brought to an adequate level, the long-term amount needed will be about in line with crop removal.

The recently developed DTPA extraction soil test for available zinc, iron, manganese and copper promises to be very good for determining the need for application of these nutrients to calcareous soils. Atomic absorption spectro-photometry greatly facilitates the determination of micronutrient cations as well as macronutrient cations. Zinc sulphate, broadcast and incorporated in the soil at 5 to 15 kilograms per hectare, is probably the most efficient method of supplying zinc for most crops. Soil applied iron has not been satisfactory on calcareous soils although use of polyphosphates as a carrier is promising. Heavy applications of animal manure may successfully prevent deficiency of iron and zinc if not too severe.

At high yield levels, various two and three-way interactions may be important. At high plant population levels both zinc and boron are required in high amounts by maize. Applied sulphate and chloride tended to be detrimental to yields of both maize and sugarbeets due to negative P-S and P-Cl interactions. Sugarbeets in Lebanon gave considerable response to sodium but interactions with applied sulphate and chloride were negative. Thus, interaction effects were more important than the direct effects for yield of maize and sugarbeets. Central composite rotatable experimental designs offer a means of studying the interaction effects of several variables with a reasonable number of treatments.

5.1. Introduction

Soils containing free calcium carbonate develop from calcareous parent materials where weathering has not been intensive enough to remove all of the carbonate. Many of the soils in areas of arid or semiarid climates are calcareous and, in warmer regions, low in organic matter. The high pH levels result in relative unavailability of phosphorus and the micronutrients zinc and iron. Under irrigation, nitrogen is apt to be limiting. The physical condition of calcareous soils is usually satisfactory because the high calcium saturation of the cation exchange complex tends to keep them well aggregated.

Where adequate water and nutrients can be supplied, the inherent productivity of calcareous soils over large areas is excellent due to favourable growing season conditions. In the Bekaa Plain of Lebanon, yields obtained include 15.8 metric tons per hectare of maize grain, 148 metric tons per hectare of sugarbeet roots and nine metric tons per hectare of wheat grain. Although natural productivity is low, the potential productivity is very good. Therefore, the diagnosis of nutrient requirements and the supply of nutrients to crops in economic amounts is a problem of the first magnitude. The social problems of making the necessary information available to farmers, motivating them to use it and providing them with the means are being solved in the developing countries. This paper will be restricted to the state of knowledge regarding fertilizing of calcareous soils. Both deficiencies and excess of nutrients and salts occur and interactions among them may be of considerable importance.

5.2. Nitrogen Fertilization

Calcareous soils are usually somewhat low in organic matter and nitrogen is often the most limiting nutrient. For most crops nitrogen needs to be applied at rates from 1 to 1.5 times the anticipated removal in the crop less the amount estimated to be available in the soil. Where generous amounts of nitrogen have been applied in the past and where soils contain layers that impede leaching large amounts of nitrate may accumulate in the soil. The Holly Sugar Company in the Texas panhandle has found it necessary to test soils of prospective sugarbeet fields down to the 1.2 metre level in order to restrict nitrogen levels to amounts unlikely to cause low sugar and impaired processing quality of the beets. Some fields were found to have more than 600 kilograms per hectare of nitrate nitrogen, an amount far in excess of that needed for sugarbeet production and resulting in low sucrose percentage beets with high impurities. Recently, the nitrate electrode has been developed and makes possible the simple and quick potentiometric determination of nitrate nitrogen by means of any pH meter equipped with a millivolt scale (Oien and Selmer-Olsen, 1969). An extracting solution containing 0.02N copper sulphate and 3 ppm nitrate-N eliminates most interferences. This gives a method of keeping track of applied nitrogen and for determining the amount needed for the anticipated crop. More elaborate incubation methods are available but offer little additional information on calcareous soils with low organic matter. A recent method (Smith and Stanford, 1971) involving autoclaving for 16 hours offers considerable savings in time over incubation methods where it is desirable to determine potentially available nitrogen.

All forms of nitrogen fertilizer are microbially transformed into nitrate within a period of a few days during seasons of the year suitable for crop growth. Nitrate is mobile in the soil and moves readily with soil moisture making it subject to leaching in case of excessive rainfall or irrigating. Thus, nitrogen fertilizer may be applied any time from just before planting up to the time the plant is well established. Side-dressing to the growing crop is one of the most efficient ways of application. Nitrogen

applied with or close to the seed may impede or prevent germination due to a salt effect. Nitrogen fertilizers are soluble salts or convert to soluble salts and thus may contribute to the salt problem in saline soils. Ordinarily the fertilizer salt would be a small part of the total salt and the main problem is to avoid concentration near the germinating seed. Where furrow irrigation is used, soil nitrate may move to the top of the ridges and accumulate as water evaporates. Here it may be relatively unavailable to plants unless washed down into the root zone by rainfall.

Ammonium nitrogen is held on the exchange complex of the soil and moves very little in this form. However, during warm weather, it is converted to nitrate. Ammonium nitrogen or forms such as urea which change to the ammonium form should not be left on the surface of calcareous soils (Terman and Hunt, 1964). The high pH and exposure at the surface will cause considerable loss of ammonia to the atmosphere by volatilization. Incorporation into the soil at time of application will prevent this.

Arid soils brought into cultivation may have a capacity to tie up several hundred kilograms of nitrogen per hectare as fixed ammonium on the clay complex (Nortland, 1966). Thus, considerable extra nitrogen may need to be applied during the first few years in order to saturate this requirement. Exclusive use of nitrate fertilizer would tend to get around this. More work is needed to determine the magnitude of the fixed ammonium problem and also on the subsequent availability of fixed ammonium under field conditions.

5.3. Phosphorus Fertilization

Calcareous soils are buffered to a pH level of 8.0 to 8.4 resulting in low availability of native soil phosphorus. Applied phosphorus quickly reverts to insoluble forms. Consequently little movement of applied phosphorus occurs. Olsen and Flowerdale (1971) have published a recent review on the subject of phosphorus in alkaline soils. Many efforts have been made to relate the phosphorus potential of the soil to phosphorus availability to crops. However, much work remains to be done since results vary for different crops at different levels of soil clays and organic matter. From a practical standpoint, the bicarbonate extractable form (Olsen et al. 1954) results in a reliable soil test showing both deficiency levels and levels of adequacy or possible excess. This test has given particularly good results in the alkaline pH range. The use of ascorbic acid as a reducing agent for forming the phosphomolybdic blue colour (Watanabe and Olsen, 1965) has increased the accuracy and ease of making the test.

In general, experimental results have shown that, to be effective on calcareous soils, applied phosphorus fertilizer should be at least 60 percent water soluble (Olsen and Flowerday, 1971). This would restrict application to monophosphates (ordinary or concentrated superphosphates) or polyphosphates which revert to monophosphates in the soil. Ammonium phosphates in which the phosphate remains mostly in the mono form would also be effective. Soluble phosphates are more effective when applied as granular rather than as finely divided material. The soluble monophosphate in the soil mostly precipitates rather quickly as the dicalcium phosphate. This precipitated phosphate has sufficient surface area to maintain a reasonably high level of soluble phosphate in the soil solution. This is in contrast to applied dicalcium phosphate which is relatively ineffective. While recovery of applied phosphorus is usually less than 20 percent during a single growing season, there is considerable residual effect and over a period of several years (Campbell, 1965) most of the applied phosphate can be recovered indicating a need for continuous monitoring of soil test levels. This also opens the possibility of applying heavy applications to last a number of years. However, there is a possibility of reducing availability of such nutrients as zinc and iron to deficiency levels for crops due to precipitation as insoluble phosphates at the pH levels of calcareous soils. Therefore, single heavy applications may not be practical both from the standpoint of effect on micronutrient availability and from the amount of capital tied up.

In the interest of minimizing the short term cost of production, band application of phosphate for row crops is about twice as effective as broadcast application in terms of crop response. However, this would result in less residual effect, so long-term savings would probably be negligible.

Amounts to apply depend on how deficient the soil is and also on how calcareous it is. Work with sugarbeets (Fuehring and Hashimi, 1967) on a Lebanese soil containing 15 percent calcium carbonate showed increasing response up to 300 kilograms of P per hectare. However, rates above 75 kilograms were probably uneconomical considering only the first years return. Rates less than about 30 kilograms per hectare may not be practical since small increments sometimes result in no increase in yield or even a decrease. Time of application for most crops is before or at the time of seeding since phosphorus is needed most during the younger stages of growth.

5.4. Other Macronutrients

Irrigated calcareous soils are usually naturally well supplied with calcium, magnesium, potassium, sodium, sulphate and chloride depending somewhat on the salt content of the irrigation water. Analysis of irrigation water is essential in determining the supply of plant nutrients as well as for the salt balance of an irrigated area.

Under non-irrigated conditions or with very low salt irrigation water, deficiencies of sulphur may develop for some crops. Sandy soils may be deficient in potassium for some crops. Sodium may be somewhat deficient for crops such as sugarbeets which benefit from having adequate sodium.

5.5. Micronutrient Fertilization

The micronutrients zinc, iron, manganese and copper tend to be less available with increasing pH levels but the occurrence of deficiencies is highly erratic. The development of atomic absorption spectrophotometry in the past decade has greatly facilitated determination of the micronutrient cations. A recently developed soil test by Lindsay and co-workers (Lindsay, W.L. and Norvell, W.A. 1969). Development of a DTPA micronutrient soil test. Agronomy Abstracts), promises to be effective in defining areas of probable deficiency for these micronutrients. This test consists of extracting the soil with the chelating agent DTPA buffered at pH 7.3. Tentative deficiency levels have been established of 4.5 ppm for iron, 1.0 ppm for manganese, 0.5 ppm for zinc and 0.2 ppm for copper. However, work is still being conducted on the critical levels for various crops. In testing various soils from a calcareous sandy area producing chlorotic groundnuts, I picked out one that tested low in both zinc and iron for the site of a study on response of groundnuts to soil and foliar application of iron and zinc. However, very little chlorosis developed. It was then discovered that 25 tons per hectare of barnyard manure had been applied the year previously. Apparently the manure tended to correct the deficiencies without appreciably affecting the soil test results. The soil test gave erroneous results under these conditions.

Deficiencies of these micronutrients result in chlorosis of varying severity. The deficiency symptoms are sometimes helpful in diagnosis but often they are complicated by multiple deficiencies or by infestation of insects or disease. It is possible to have considerable response to zinc when check plots show no noticeable deficiency symptoms.

Zinc deficiency is probably most pronounced in maize especially at high population levels. Relatively small amounts of zinc are required. Zinc sulphate is effective and

is the form usually used since it is relatively inexpensive. Foliar applications or dormant sprays are usually used on fruit trees. For soil application, six to eight kilograms of actual zinc per hectare broadcasted and incorporated are usually sufficient although maize on a highly calcareous soil may respond up to 90 kilograms per hectare (Fuehring et al. 1969b). One application is usually sufficient for several years because zinc does not leach or move appreciably in the soil. Use of chelated zinc will reduce the amount needed by a factor of from about two to five. Chelated zinc is more expensive and the residual effect would be less.

Plant tissue analysis has been used to diagnose zinc deficiency in fruit trees, maize, sugarbeets, etc. However, levels vary with age of and type of tissue and also depends on the balance with other elements.

Iron deficiency shows up as interveinal chlorosis of leaves and is more difficult to correct than zinc deficiency since soil application results in rapid reversion to unavailable forms. Some plant species, sorghum for example, are more susceptible to iron deficiency than others. One method of overcoming it is to avoid using susceptible crops. Foliar sprays with ferrous sulphate will result in greening of foliage but the effect is usually only temporary. Chelated iron is more effective for soil application than inorganic forms but at the pH of calcareous soils most chelates are unstable. Geigy's chelate 138 is stable in calcareous soils but is expensive to use. Mortvedt and Giordano (1971) have been working to find practical ways of applying iron in calcareous soils, but much more work is needed. They have had some success with fluid polyphosphate mixtures as carriers of iron. Field application requires considerably more work in that the amount of iron that can be carried is limited by its solubility in the mixture. Also more phosphate than required may have to be applied in order to get sufficient iron.

Manganese and copper are much less apt to be deficient on calcareous soils than iron and zinc. If deficient the sulphate forms are commonly applied to the soil. Many soils have large amounts of available manganese and copper which may tend to upset the balance with iron and zinc. Addition of manganese or copper should be avoided where soil test levels indicate more than adequate amounts already present.

Some calcareous soils may be deficient in boron. However, many irrigation waters carry considerable boron. With high boron irrigation water toxicity to plants may be a problem as boron accumulates. Since the margin between boron deficiency and toxicity is rather narrow, caution is needed to get uniform distribution in the soil and to avoid a boron build-up through repeated application. Hot water soluble boron is the most common soil test used. Crops susceptible to boron deficiency include alfalfa, sugarbeets and corn at high plant population levels. Areas where the irrigation water contains more than 0.1 ppm boron will probably have enough for most crops. Wilcox and Durum (1967) give a list of crops with increasing sensitivity to boron toxicity from 4 ppm down to 0.3 ppm boron in the irrigation water.

5.6. Organic Materials as Fertilizers and Soil Amendments

The use of organic wastes as fertilizers is very ancient since it not only replaces nutrients in the soil but also disposes of a pollutant. However, in the developed countries at least, the use of commercial chemical fertilizers offers considerable advantages in the form of ease and precision of application. The cost of handling bulky organic materials such as barnyard manure tends to be greater than the cost of applying needed nutrients through concentrated chemical fertilizers. However, since the organic waste material must be disposed of, application to the land is a good way of utilization as long as human wastes do not constitute a disease problem.

Organic materials as fertilizers have the advantage of being slow-release sources of nutrients which also tend to be balanced. Alternative uses as feed or fuel may preclude use as fertilizer in many parts of the world.

Plants take up practically all nutrients in the inorganic form which means that organic sources must first be broken down before plants can use them. There is no definite evidence that food grown with strictly organic fertilizer sources is more nutritious or more flavoured.

Most calcareous soils are naturally low in organic matter and a build-up of organic matter would tend to buffer them from the standpoint of nutrient sufficiency as well as the physical condition of the soil. The residues (stems, leaves, roots, etc.) of most high yielding crops will tend to build up soil organic matter if left in the field. However, the organic matter level in the soil tends to equilibrate with climatic conditions as well as cultural practices. In hot climates, biological activity in the soil is very great and organic material breaks down rapidly. So organic matter build up in the soil is not an efficient process since much of it tends to be rapidly decomposed. Also, especially in the initial rapid breakdown, substances toxic to seed germination and plant growth may be released and temporarily inhibit or impede crop growth. Crop residues low in nitrogen and incorporated into the soil will result in a tie-up of soil N as the micro-organisms expand rapidly in numbers and mass and utilize all available N. Large amounts of bulky organic residues may impede cultivation and seeding practices.

The use of organic material to alleviate a poor physical condition in the soil may be important in some cases. Calcareous soils tend to be well aggregated and soil structure is usually good. Where topsoil has been removed in land levelling to improve surface irrigation, yields are often very poor due to lack of available nitrogen, phosphorus, zinc and sometimes iron. The physical condition may also be poor due to compacting during levelling. Adding large amounts of commercial fertilizer will partially correct the adverse conditions but considerable expense is involved. Adding large quantities of livestock manure and working it into the surface soil is effective in alleviating the condition but often manure is not available. Probably the best way of avoiding trouble from land levelling is to arrange operations so that 15 to 20 cm of the topsoil is stockpiled and then returned after the grade has been established. While this may double the cost of levelling, improved yields the first year or two will probably more than pay the extra cost. Soils with reasonable amounts of organic matter (more than 1%) in the topsoil would be most affected by removal while soils with low organic matter (less than about 0.3% as in desert soils) would probably not be appreciably affected.

A build-up of organic matter in soils is sometimes advocated in order to enhance the water holding capacity. This would be of very minor importance in most soils since the probable increase in available water holding capacity would be in the order of one or two percent at most.

Heavy rates of barnyard manure applied to the soil may be a means of alleviating deficiencies of micronutrients such as iron and zinc which may be severely lacking in availability in some calcareous soils.

Use of organic materials as fertilizers depends on a number of economic factors. Alternative means of utilizing or disposing of the materials and alternative sources of plant nutrients are important factors. Calcareous soils are usually well aggregated so problems related to poor soil structure are usually not very important.

5.7. An Experimental Design for Plant Nutrition Studies

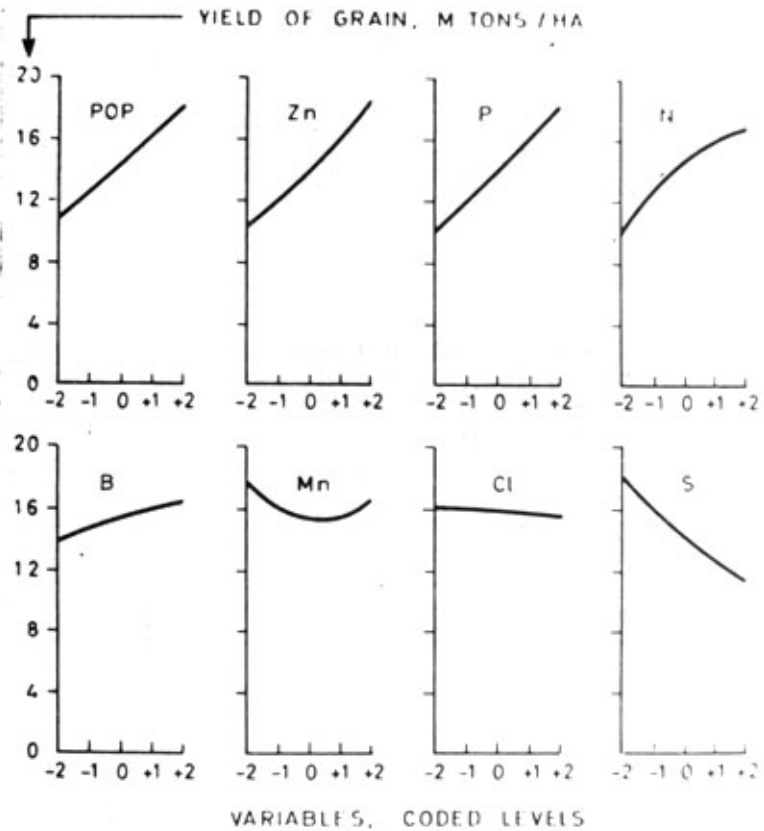
As crop yields are pushed up toward theoretical maxima, the supply of nutrients becomes more of a problem not only directly but as interaction effects between or among two or more elements. Conventional factorial experimental designs allow determination of these effects, but as the number of levels and factors studied is increased the number of plots required rapidly becomes unwieldy. The use of rotatable central composite designs (Cochran and Cox, 1957) is one means of compromising. A complete two-level factoria consists of 16 points for four variables, 32 for five, and 64 for six. A central point at the middle level of each variable and additional very high and very low points are added making five levels for each variable. For four variables this would make 25 treatments. For exploratory work, the treatment with all variables at the middle of five levels is repeated seven times resulting in six degrees of freedom for error and a total of 31 plots. For more precise experimental work, the whole set of 25 treatments can be replicated two or more times. I find that two replications of the four variable design giving a total of 50 plots and 24 degrees of freedom for error results in a workable size experiment. Cochran and Cox (1957) give five and six variable versions of the design using one-half of a complete factorial for the two main levels. However, the three-way interactions are confounded when this is done. I have found the three-way effects to be more important than the direct or two-way effects in many cases so I believe a complete two-level factoria should be adhered to even at the expense of using a greater number of treatments. The five levels can be set on an arithmetic scale if the area of probable response can be somewhat approximated on a relatively narrow range of values used. Where a wider range may be desirable, as with micronutrients, a logarithmic scale can be used. A logarithmic scale to the base two (doubling the rate at each step) will cover a fairly wide range. A disadvantage of the log scale is that a zero rate is never attained. In order to facilitate calculations and interpretation the levels are coded on a scale of -2, -1, 0, +1 and +2 with the extremes varied somewhat from this according to the number of variables involved. The variables can involve any factors that can be set quantitatively such as applied nutrient levels, plant population density and irrigation interval.

The data is analysed in the form of a quadratic regression equation by determining the statistical significance of the individual regression coefficients. Use of a computer greatly simplifies the calculations once they have been programmed. The equation can be solved for the combination of variables resulting in maximum yield and when plant analysis is used in conjunction with the experiment, critical levels of nutrients in various plant tissues at various stages of growth can be determined.

5.8. Plant Nutrient Interaction in Maize

Work in the Bekaa Plain of Lebanon during the 1960's (Fuehring et al. 1969b) resulted in maize grain yields up to 15.8 metric tons per hectare, about as high as anywhere in the world. In a series of eight irrigated field experiments maximum yields required high levels of plant population and applied nitrogen, phosphorus, zinc and boron. Levels of applied sulphate and chloride needed to be low (Figure 1). Usual rates of application for N, P, S, and Cl were 37, 75, 150, 300 and 600 kg/ha which were coded as -2, -1, 0, +1, and +2 respectively. Corresponding rates for Zn, Mn, and B were 11, 22, 45, 90 and 180 kg/ha. Plant population was varied from 40 to 93 thousand plants/ha. Fertilizers were applied at seeding time in a broad band about 5 cm below the seeds. It was found that high rates of N and P (around 300 kilograms of each per hectare) were required for maximum yields. The N levels are in line with N removal in the harvested crops but P is far in excess of that removed and most of the applied P remained in the soil. It would appear that relatively heavy initial applications were necessary on these calcareous soils (around 15% CaCO₃) but subsequent applications could be reduced in line with the amounts needed to keep soil test levels at an adequate level. This is an area where much more work is needed.

Figure 1. Yield of maize grain (from regression equation) as affected by plant population (POP) and application of Zn, P, N, B, Mn, Cl, and S in a series of eight experiments. When not varied, plant population, Zn, P, N, and B were held at high levels and Mn, Cl, and S at low levels.



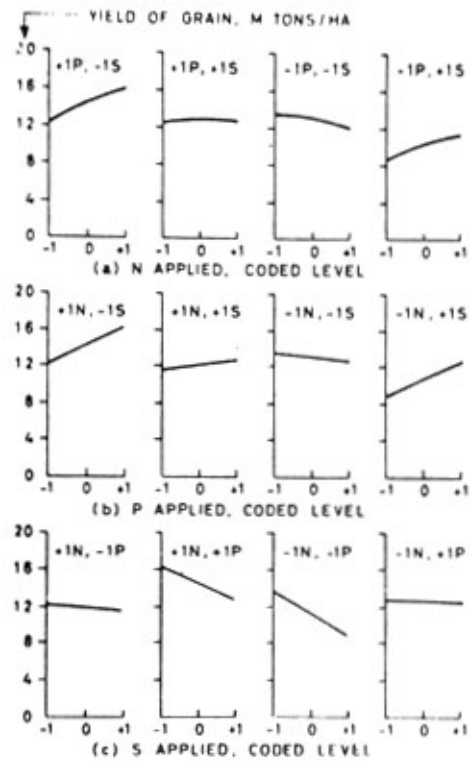
The amount of P fertilizer to be applied for maximum yields of maize varies from around 300 kilograms per hectare on a 15% CaCO_3 soil in Lebanon to about 30 kilograms per hectare on a nearly neutral soil on the High Plains of eastern New Mexico where amounts in excess of 30 kilograms were found to have an increasingly depressing effect on grain yield of maize. The long-range requirement of fertilizer P would probably be the same but it would have to be applied at more frequent intervals on non-calcareous soils.

In three out of four experiments in Lebanon, there were relatively large negative P-S interactions. The P-Cl interaction was negative in all three of the experiments where it was present. Thus, high rates of either sulphate or chloride tended to negate the positive response to phosphorus. The N-P-S three-way interaction was negative and of considerable magnitude indicating that sulphur needed to be kept low at the necessary high levels of nitrogen and phosphorus. Under saline conditions or with high salt irrigation water it may not be possible to keep sulphate and chloride low enough to obtain very high yield levels.

Numerous reports in the literature (Stukenholtz *et al.*, 1966) indicate a positive P-Zn interaction with excessive applied phosphorus resulting in or intensifying the deficiency of zinc. The effect appeared to take place in the plant roots rather than in the soil. The work in Lebanon resulted in both negative and positive P-Zn interactions with no definite effect apparent.

Work in the greenhouse (Koukoulakis, 1967) using two calcareous soils from Lebanon resulted in greater zinc availability to maize plants grown in the more calcareous of the two soils (33% CaCO_3 vs 14%). It was found that the roots of the plants grown in the more highly calcareous soil had more calcium, as expected, and about the

Figure 2. Effect of negative N-P-S interaction on yield of maize grain (from regression equation).



same level of phosphorus (Table 1). However, less phosphorus was translocated to the plant tops indicating a tie up of phosphorus in the roots, probably with calcium. The plants grown in the more calcareous soil had less zinc and manganese in the roots and a higher concentration of the two in the tops. It was postulated that the phosphorus in the roots of the plants grown on the less calcareous soil was more active (less tied up by calcium) and tended to hold the zinc and manganese in a less active form, thus tending to prevent translocation of zinc and manganese to the tops. Thus, the excess calcium of calcareous soils reacts with phosphorus directly in plant roots and indirectly affects the translocation of micronutrients from roots to tops.

Table 1. Composition of greenhouse-grown maize plants. American University of Beirut. 1967.

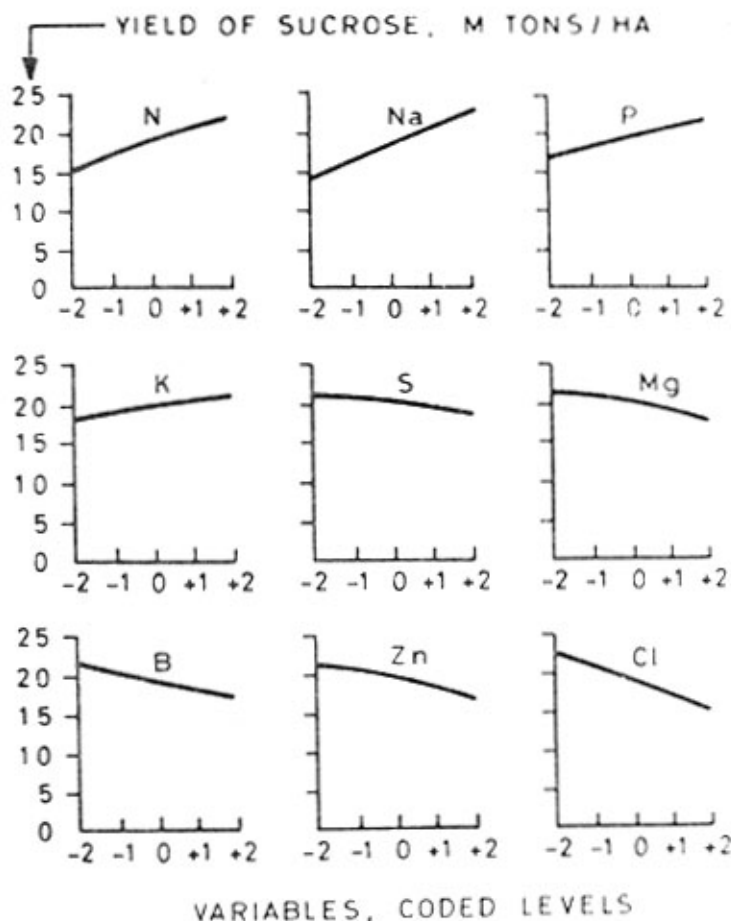
| Maize Plants | Soil 1 14% Lime | Soil 2 33% Lime |
|---------------|--------------------|--------------------|
| P, % Tops | .251 | .155 |
| Roots | .208 | .219 |
| Ca, % Tops | .5 | 1.3 |
| Roots | 3.6 | 7.7 |
| Zn, ppm, Tops | 32 | 61 |
| Roots | 177 | 117 |
| Mn, ppm, Tops | 56 | 72 |
| Roots | 453 | 170 |

In the Lebanon studies, maize responded to zinc and boron at rates up to 90 kilograms per hectare especially as the plant population level was increased. The Zn-B-plant population interaction was positive in all three experiments in which it appeared indicating increasing need for all three as the yield level is pushed up. The P-B-plant population three-way interaction was also positive. On a non-calcareous soil in New Mexico, the N-Zn-B interaction was positive for grain yield. However, the optimum levels required were in the order of six kilograms per hectare for zinc and three for boron, an order of magnitude smaller than on the calcareous soil. It appears that maize has high requirements for both zinc and boron as plant population and yield levels are increased.

5.9. Plant Nutrient Interaction in Sugarbeets

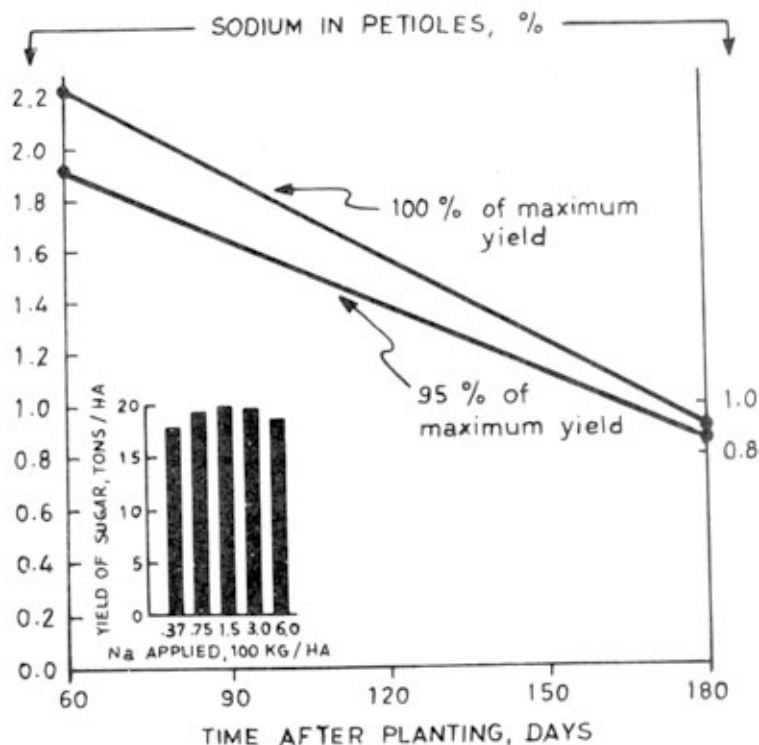
Fuehring *et al.* (1969a) summarized the results of 13 multivariate field experiments conducted from 1960 to 1966 in the Bekaa Plain of Lebanon. Yields of sugarbeets were obtained as high or higher than anywhere in the world. Yields up to 25 metric tons of sucrose compare favourably on an annual basis with yields obtained for sugar cane in Hawaii. In general, high rates of applied nitrogen, phosphorus and sodium were necessary along with low levels of sulphate, chloride, zinc and boron. The interaction effects tended to be more important than the direct effects except for the rather large positive direct effect of nitrogen on yield. The Na-S and Na-Cl interactions were negative indicating a need to keep sulphate and chloride levels low in order to get maximum response to applied sodium. Thus, sodium chloride and sodium sulphate would be poor sources of sodium. Sodium nitrate would probably be the best source of sodium as long as the total supply of nitrogen is adjusted to the amount required. The response

Figure 3. Yield of sucrose from sugarbeets (from regression equation) as affected by applied N, Na, P, K, sulphate, Mg, B, Zn, and chloride in a series of 13 experiments. When not varied, N, Na, P, and K were held at high levels and sulphate, Mg, B, Zn, and chloride were held at low levels.



to sodium would depend on the supply in the soil and particularly on the level in the irrigation water. Water with more than one milliequivalent per litre would probably have sufficient sodium. The response to applied sodium was maximized at the rate of 150 kilograms per hectare with irrigation water having 0.28 milliequivalents per litre of sodium. Petiole analysis (Fuehring and Hashimi, 1967) indicated a critical level of around two percent early in the season tapering off to around one percent near the end of the growing season. Excess sodium tended to decrease yields so a soil, water and plant petiole analysis is necessary to determine whether additional sodium would be beneficial to yields.

Figure 4. Effect of applied sodium on yield of sucrose and sodium concentration in petioles.



Nitrogen at the rate of 150 kilograms per hectare (Fuehring and Hashimi, 1967), was enough for nearly maximum yields of sugar. These were on fields that had been fallow the previous year and presumably had accumulated considerable available nitrogen. Work in the United States has determined that it takes about 10 pounds of nitrogen for each ton of sugarbeets produced. Thus, if the amount of nitrate-N accumulated in the profile is known and the probable attainable yield level is known, the amount of fertilizer N required can be determined roughly by difference. The critical level of nitrate-N in the sugarbeet petioles was found to vary from around 4 000 ppm at 60 days after planting to about 300 ppm at 180 days after planting (Fuehring and Hashimi, 1967).

In general, yield of sucrose increased as phosphorus application was increased up to 300 kilograms per hectare. Since there is much more phosphorus than actually used, the balance would be carried over and could be used by subsequent crops. Periodic soil testing would be necessary in order to monitor the available phosphorus levels in soils and to determine when additional phosphorus would be required.

Figure 5. Effect of applied nitrogen on yield of sucrose and nitrate-N concentration of petioles.

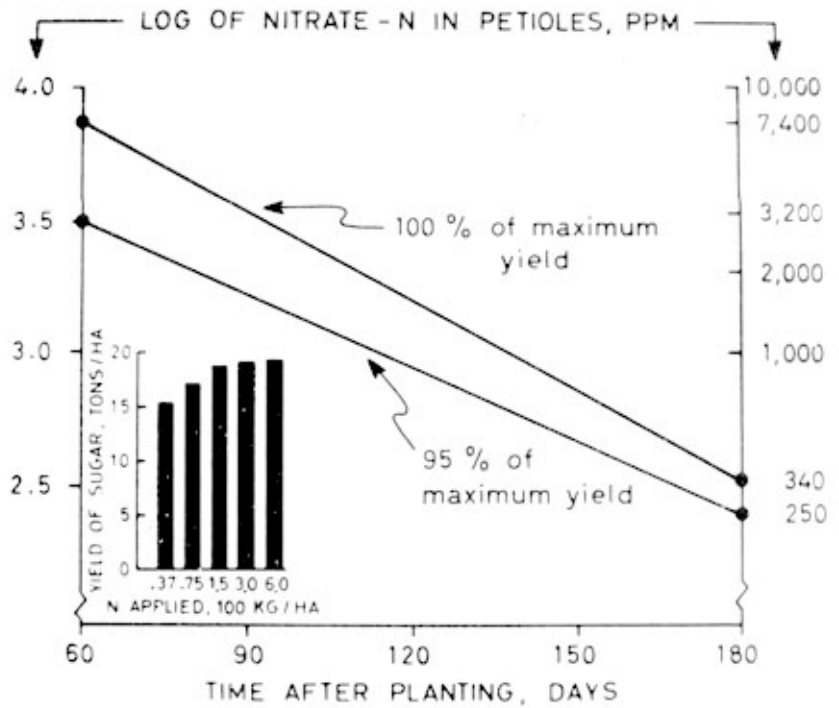
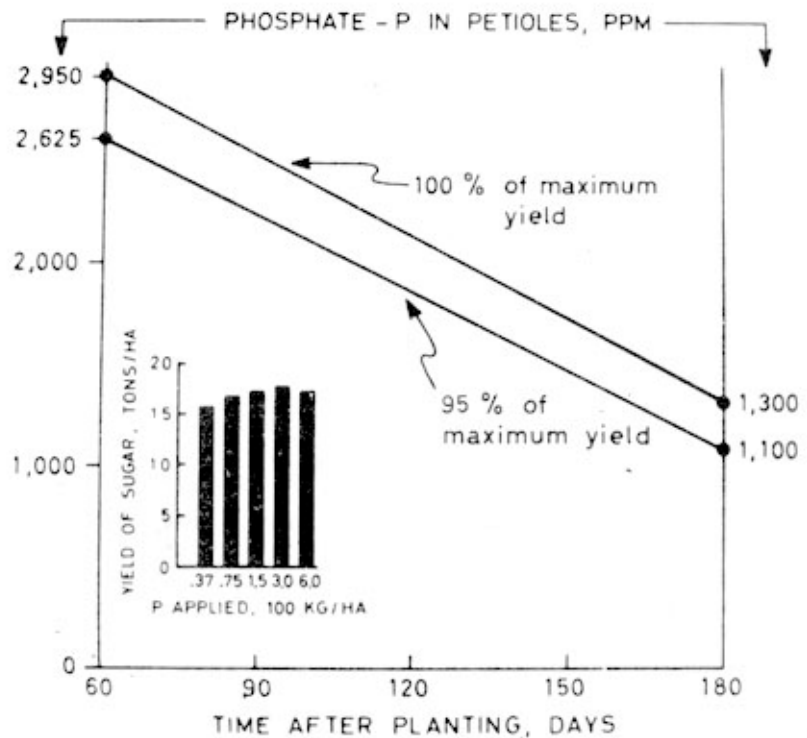


Figure 6. Effect of applied phosphorus on yield of sucrose and phosphate-P concentration of petioles.



In general, the high boron and zinc levels necessary for high corn yields tended to decrease yields of sugarbeets. The N-Na-Zn three-way interaction was negative and of considerable magnitude so, with nitrogen and sodium at high levels, zinc would have a depressing effect on yield. Zinc also had important interactions with nitrogen (negative) and chloride (positive) which contributed to its general depressing effect. The linear effect of boron was consistently negative and accounted for much of the net negative effect of applied boron on sucrose yields.

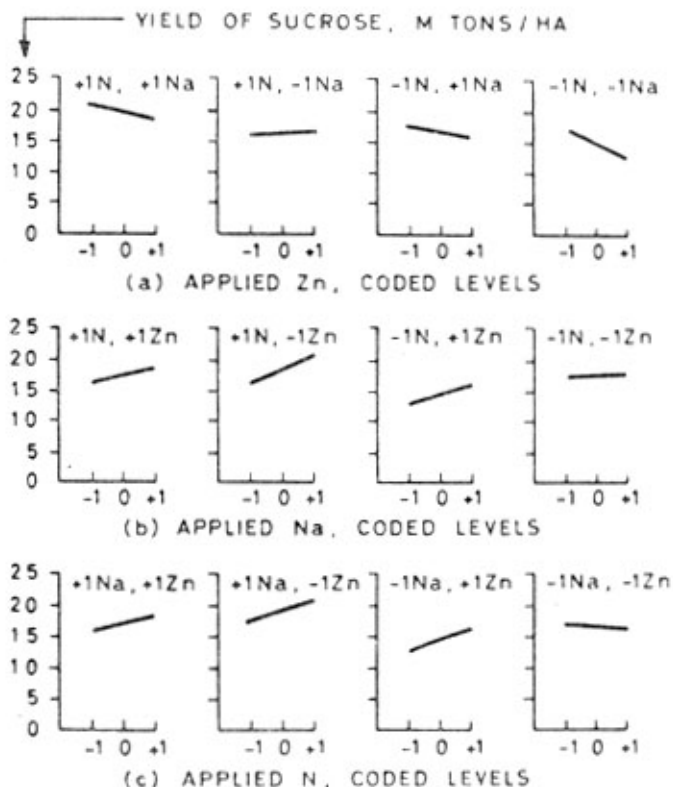


Figure 7. Effect of negative N-Na-Zn interaction on yield of sucrose of sugarbeets (from regression equation).

The general depressing effect of sulphate and chloride on yields of both maize and sugarbeets is probably associated with the cation-anion balance in plant tissues. Noggle (1966) found that the greater the proportion of organic anions (difference between total cations and total anions on an equivalent base) in plant tissues, the greater the yield for a number of species.

5.10. Response of Cotton to Fertilizers

Luckhardt and Ensminger (1968) gave a comprehensive review of fertilizer use on cotton. The nitrogen requirement of a cotton crop amounts to about 60 lb per bale of lint produced so the amount to be applied depends mostly on the probable yield level with allowances for amounts present in the soil profile (soil test for nitrate-N). Thus, high yielding cotton (5 bales per acre) may respond up to 400 lb of applied N per acre where original amounts available in the soil are low. Excess nitrogen tends to delay flowering and should be avoided. On sandy soils at least part of the nitrogen should be applied as an early sidedressing. Cotton is sensitive to phosphorus deficiencies especially during the boll forming stage and phosphorus should be added according to soil test. Initial requirement is low so sidedressing up to time of first bloom is effective. Potassium

should be applied if soil tests are low (less than 60 ppm on sandy soils to 100 ppm on fine-textured soils) but most calcareous soils have adequate K levels. Zinc and iron may be deficient for cotton on some calcareous soils and can be remedied with spray applications.

Plant tissue analysis at time of initial bloom allows addition of nutrients before the time of maximum uptake about 45 days later. At the early bloom stage 18 to 20 thousand ppm nitrate N in the petioles of the youngest mature leaves may be necessary in order to maintain nitrogen above the 2 000 ppm critical level throughout the growing period. The phosphorus critical level in petioles is 1 000 ppm and is relatively stable throughout the season. A value of 3 500 ppm total phosphorus in leaf blades has also been used as the critical level. The critical level for potassium in leaf petioles is 4 to 5% at first bloom dropping to about 2% late in the season.

5.11. Response of Alfalfa to Fertilizers

Wagner and Jones (1968) have reviewed the literature on fertilization of high yielding forage crops. High yields of alfalfa (6 to 10 tons per acre) remove large quantities of nutrients from the land and long time intensive cropping will result in considerable need for phosphorus (70 to 120 lb P_2O_5 removed per acre per year) and possibly potassium (250 to 500 lb K_2O removed per acre per year). Soil tests are the best indicators of initial P and K levels. Where deficient levels are indicated, fairly large amounts are usually added initially in order to build up to adequate levels with maintenance amounts added thereafter. The time and method of adding the maintenance amounts is relatively unimportant as long as distribution is uniform. High yielding non legume forage crops would require similar amounts of phosphorus and potassium along with large amounts of nitrogen (up to 800 lb per acre).

5.12. Response of Olives to Fertilization

Olives are often grown on soils unsuitable for other crops and low in nutrients and thus usually respond well to application of fertilizers. De Geus (1967) has reviewed the fertilization of olives. When nutrients are short, olive trees may be thrown into bearing alternate years being unable to produce both fruit and the new growth necessary for the next years crop. Olives retain their leaves for three years and during this time they serve as a storehouse of nutrients decreasing during fruit filling and increasing at other times of the year. Foliar analysis is used but the time of year and age and location of leaves sampled must be carefully defined. Critical levels for nitrogen in leaves have been given of from 1.2% (California) to 1.75% (high yielding trees in Tunisia). The phosphorus critical level is around 0.10 to 0.15% and the potassium critical level varies from 0.8 to 1.2%, the higher figure needed on more calcareous soils and at higher yield levels. The foliage sampled is from flower bearing twigs during spring or during winter when levels are relatively stable.

Levels of fertilizer recommended for high yielding olive trees (200 lb or more) are 1 to 2 lb N, $1/3$ to $2/3$ lb P, and 1 to 2 lb K. Under irrigation and very high yields (400 lb per tree) doubling of these amounts may be necessary. Continued application over a period of years may result in an accumulation of P and K in the soil. Foliar analysis gives a way of monitoring nutrient levels over a period of time. In order to insure adequate fruit set the fertilizer should be applied some time prior to flower initiation. Placement should be in the root zone and deep enough to prevent soil drying out. Concentrating P in a band or in a few places around the tree will tend to prevent rapid fixation of P into unavailable forms. On the more fine textured soils, soil K may be adequate and fertilizer K unnecessary. A soil test would be in order under these circumstances.

5.13. Response of Citrus to Fertilization

Fertilizer use on citrus has been reviewed extensively by Reitz and Stiles (1968) and De Geus (1967). Nitrogen is usually the most limiting nutrient factor. Leaf analysis is probably the best way of monitoring the levels of nutrient available as well as the balance among nutrients. Soil analysis values are less effective because of the difficulty of securing samples representative of the entire zone from which roots draw nutrients. Non-uniform placement of previous fertilizer applications is also a factor. An initial soil test before establishment of the citrus grove may have considerable value with regard to phosphorus levels. Chapman's (1960) leaf analysis values (4 to 7 months old spring cycle from fruit bearing terminals) consistent with top performance are probably the ones most pertinent to citrus grown on calcareous soils. Values given are (in percent of dry matter) 5.0 Ca, 0.4 Mg, 1.0 K, 2.4 N, 0.12 P, 0.30 S, 0.05 Cl and (in ppm) 75 B, 5 Cu, 60 Fe, 35 Mn, 0.20 Mo and 25 Zn. The values for the following (in ppm of dry matter) should be less than 0.05 As, 100 Br, 0.10 Cr, 20 F, 0.50 Li, 0.40 Co and 0.40 Ni.

High yielding oranges may respond in yield up to 300 to 400 lb per acre of applied N. However, where colour is important, as with oranges sold as fresh fruit, excessive N may result in green coloured fruit. Zinc and iron if needed are usually applied as foliar sprays.

5.14. Response of Vegetable Crops to Fertilization

Since vegetables are high value crops used directly as human food adequate fertilizer application usually constitutes a small part of the total cost of production. Lorenz and Bartz (1968) have reviewed fertilization practices needed for production of vegetables. Amounts of phosphorus and potassium are applied at rates high enough to bring soil test levels up to high levels. Nitrogen should be applied at rates somewhat greater than the anticipated amount found in the crop at time of harvest.

A study in Lebanon (Fuehring, 1969) on fertilizing and irrigation of tomatoes on calcareous soil indicated a need for a balance of applied N, P and S in order to decrease the cracking of Big Boy tomatoes. Irrigations could be made at less frequent intervals when N, P and S were in balance. While S had little influence on total yield, it increased marketable yield by reducing cracking. However, a variety more resistant to cracking would probably not show the response to S. Work by Zarei (1966) in Lebanon indicated split application of N (at initial fruit set and 45 days later) to be superior to applying all N at time of transplanting. There was also considerable positive response to Zn application where the N application was split.

A series of field experiments on potatoes (Fuehring and Ghurayyib, 1969) on a calcareous soil in Lebanon indicated response to N, P and K at high levels (300 kg of each per ha), and Mg at levels around 150 kg per ha. In general, S, Cl and Zn resulted in yield decreases. The K and Mg response was chiefly the result of negative interactions with S and Cl.

5.15. Cropping Systems and Maintenance of Soil Fertility

Cropping systems to be used depend on numerous economic as well as agronomic factors. Where two or more crops are needed and can be grown in an area, rotation of crops from year to year offers several advantages such as control of diseases, weeds, insects and nematodes. Crops with different rooting patterns tend to vary the areas of nutrient extraction from the soil. Some crops (such as maize or fruit trees) do well under monoculture while others (sugarbeets) run into difficulties. Adequate fertilizer application tends to overcome nutritional aspects of monoculture but this implies availability and use of soil testing facilities. Legume forage crops will provide livestock feed as well as build up soil nitrogen supplies. The feasibility of their use depends on having a use for the produced forage as well as the availability of an alternate source of nitrogen. Legume seed crops do little to build up soil nitrogen although they will need no applied N if the proper rhizobium are present either by inoculation of the seed or presence in the soil from previous crops.

The use of fallowing as a means of increasing available soil N (through breakdown of soil organic matter during the fallow period) tends to decrease the level of soil organic matter over a period of time and is a wasteful use of land. However, if land is more plentiful than water and if fertilizer N is not available, fallowing offers a means of increasing water use efficiency, in the short run at least.

The use of green manure crops to be incorporated into the soil will tend to concentrate available nutrients for the next crop but is wasteful of water in that no direct benefit is derived.

The use of improved varieties of crops is essential in utilizing high levels of fertility. The recently developed short-statured small grain varieties can produce high yields of grain in the presence of plentiful soil nitrogen without becoming severely lodged. Also, the potential of new crop varieties cannot be realized unless the required plant nutrients are also made available.

In general, fertilizing and other practices resulting in high yielding crops will tend to conserve and build up fertility levels in the soil especially as crop residues are retained on the soil.

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SOME PHYSICAL PROPERTIES OF HIGHLY CALCAREOUS SOILS
AND THE RELATED MANAGEMENT PRACTICES

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SUMMARY

The paper presents some physical properties of the highly calcareous soils and the related management practices. The true evaluation of their texture must take into account the inherent particle size distribution of the CaCO_3 which can be found in various size ranges. Generally, in a fine textured soil most of the CaCO_3 is within the clay and silt fractions. The highly calcareous soils, regardless of their texture, have the same moisture depletion pattern and this entails frequent irrigation. It has been found that by following the right irrigation regime, it was possible to double the dry weight of maize plants. The increase in CaCO_3 content, especially above 35% has adversely affected the vegetative growth of maize plants.

The diffusivity of water through calcareous soils was found to be higher than through non-calcareous soils of similar texture. Increasing CaCO_3 up to 10 or 15% increased diffusivity while a further increase up to 20 or 25% relatively reduced it. In highly calcareous soils, it seems that the size distribution of the carbonate had more effect on diffusivity than did its total content. A study on infiltration and redistribution of water in a highly calcareous soil is presented to show the moisture profile development during redistribution, its relation to the F.C. concept and its importance to the water storage capacity of the soil.

Soil crusting is discussed in relation to the moisture regime effect on seedling emergence and factors affecting its strength. Heavy water applications delayed crusting but produced a thicker crust. The most apparent feature of the crust is its higher bulk density than the subcrust. A high rate and percentage of emergence could be obtained if the moisture tension of the crust is kept relatively low and the right planting technique and depth of seeding are followed. The relative importance of the factors affecting crust strength follow the sequence, bulk density > moisture tension > silt > silt + clay > sand > clay > CaCO_3 .

Experiments are presented to show that the tilth of these highly calcareous soils could be affected by the use of different tillage implements and techniques. Selecting the right plough, depth of ploughing and the optimum moisture content at time of ploughing have improved the soil tilth.

6.1. Introduction

Calcareous soils are of wide occurrence in the Near East Region, under arid and semiarid climates, where the presence of CaCO_3 in considerable amounts, sometimes above 20 percent, is not uncommon, Kadry (1972). High CaCO_3 content, especially the active fraction, affects the chemical characteristics of the soil, its fertility and its physical properties. The author, while working in the Soils and Water Department, Faculty of Agriculture and the Land Reclamation and Improvement Institute of the University of Alexandria, had the chance to study some of the physical properties of the highly calcareous soils of the north-western region of Egypt. It is the purpose of this paper to present and discuss some of these properties and the practical management practices that could be applied.

6.2. Particle Size Distribution

Particle size determination is being carried out in most of the soils laboratories as routine work. Not only the relative proportions of the different size fractions can be obtained from this determination, but also some other physical and chemical characteristics can be deduced.

It is common practice during the pretreatment of mineral soils to remove all their CaCO_3 , but such a practice is questionable for highly calcareous soils where the calcium carbonate is found not only as a cementing agent but also as a distinct component of the mineralogical composition of the soil in various size ranges. This inherent particle size distribution has to be taken into account to obtain a true evaluation of the soil texture.

If the CaCO_3 is retained, the particle size distribution obtained will depend on the dispersion technique and, therefore, the selected technique may be said to define arbitrarily the mechanical composition. Day (1965) reported that mixtures of NaPO_3 and Na_2CO_3 have proved particularly effective as a dispersing agent and have made it possible to disperse calcareous soils without the prior removal of alkaline earth carbonates. The optimal concentration of the dispersing agent is best determined by preliminary tests. Concentrations of 0.010, 0.015, 0.20 N of sodium hexametaphosphate were tried in the final suspension and the results indicated that in this concentration range, no more dispersion occurred by increasing the concentration of the dispersing agent above 0.01 N, Salim and Massoud (1966). Dispersion of calcareous soils can be obtained by ultra-sonic vibration techniques, Watson (1971).

The inclusion of CaCO_3 in the respective fractions, without considering its own size distribution, may lead to a misleading interpretation of the behaviour of highly calcareous soils when such interpretation is based on particle size distribution alone. For example, the minute silicate colloidal particles are accompanied by a tremendous number of adsorbed cations, while CaCO_3 particles of the same size are not. Likewise, the presence of very fine particles of CaCO_3 is believed to be responsible for the chlorosis of many crops which may not occur if these particles are made up of clay minerals. Similarly, a trained soil surveyor may find it difficult when using the feel method, to match the texture of a highly calcareous soil found in the field with that of the laboratory, since both methods are influenced by the high CaCO_3 content of the soil; his estimate would be rather erroneous if the CaCO_3 had been removed. Therefore, for highly calcareous soils it is desirable to complement the particle size distribution of the soil with that of its CaCO_3 .

The determination of particle size distribution, of CaCO_3 can be achieved by analysis of the whole soil sample with and without removal of its lime content. For a given size fraction the difference between these two analyses gives the amount of CaCO_3 present in

that size range. The same value could be obtained by determining the CaCO_3 content in a given size fraction taken without prior removal of the soils' carbonates. Moreover, the determination of the very fine fraction of CaCO_3 in the silt and clay size range, which is a measure of the potentiality of calcareous soils to cause chlorosis (active lime), can be achieved by adsorption methods, Drouineau (1942), Yaalon (1957).

The significance of knowing particle size distribution, both with and without removal of CaCO_3 , can be recognized from analysis of the data reported by Menon (1971) on the soils of the Ghab project in Syria, given in Table 1.

Table 1. Soil Particle and CaCO_3 Equivalent Size Distribution of Pilot Area, Ghab Project, Syria

| | Clay <0.002 mm % | Silt 0.05-0.002 mm % | Sand 0.05-2.0 mm % | CaCO_3 % |
|---|------------------------|----------------------------|--------------------------|----------------------|
| Before removing carbonates | 28 | 43 | 29 | 68 |
| After removing carbonates | 9 | 11 | 12 | |
| Distribution of carbonates | 19 | 32 | 17 | |
| % loss due to removing carbonates | 68 | 74 | 60 | |
| Distribution of carbonates as percent of total CaCO_3 equivalent | 28 | 47 | 25 | |

The data show that the texture of such soils would be clay loam if determined in the laboratory without removing CaCO_3 , although the clay and silt fractions are those usually found in a non-calcareous loamy sand or sandy soils. The same soil would probably be classified as silt clay by a soil surveyor in the field. To avoid such confusion and a misleading interpretation, data on particle size distribution of calcareous soils ought to be presented as shown in Table 1. The data also show that the non-calcareous clay and silt fractions amount to 20 percent compared to a corresponding lime content of 51 percent, which is very high and creates special fertility problems.

The CaCO_3 can be found in various size ranges depending on the soil forming factors, which are mainly the parent material and climate. Therefore, knowledge of the particle size distribution of the calcareous and non-calcareous soil materials is of significance in the study of soil formation and leaching of carbonates.

In a study on soil water diffusivity through the Egyptian calcareous soils by Salim and Massoud (1966), surface samples were collected from the region west of the Delta and analysed for their soil particle and CaCO_3 size distribution. The result of the analysis is shown in Table 2.

Table 2. Soil Particle and CaCO₃ Equivalent Size Distribution in Calcareous Soils from West of the Delta, Egypt

| Soil Texture | Soil Particles-% | | | Calcium carbonate-% | | | Total CaCO ₃ -% |
|-----------------|------------------|------|------|---------------------|------|------|----------------------------|
| | clay | silt | sand | clay | silt | sand | |
| Sandy clay loam | 20 | 22 | 58 | 27 | 39 | 34 | 26 |
| Sandy clay loam | 27 | 25 | 48 | 29 | 32 | 39 | 46 |
| Sandy loam | 17 | 11 | 72 | 27 | 13 | 60 | 22 |
| Sandy loam | 17 | 6 | 77 | 9 | 37 | 54 | 7 |
| Sand | 5 | 2 | 93 | 4 | 0 | 96 | 38 |
| Sand | 3 | 1 | 96 | 0 | 0 | 100 | 11 |

The results show that within the same textural class, the total CaCO₃ content may vary considerably and yet it may be the same for different textural classes. As a general trend, the highest percentage of calcium carbonate content is within the silt and clay fraction in the case of sandy clay loam soils and within the sand fraction in the sandy loam and sandy soils. The same trend follows the aridity of the climate since the sandy clay loam soils were taken from Mariut Project and the rest of the samples further to the south.

6.3. Moisture Characteristics

Information on the moisture characteristics of calcareous soils is imperative to the proper planning of their irrigation regime. The moisture tension drying curve is of practical significance in determining the range of soil moisture available for plant growth and its depletion pattern. But to what extent would the presence of CaCO₃ affect this range and that pattern in soils of different mechanical composition? To find an answer to this question, a study was carried out on the moisture characteristics of the highly calcareous soils of Mariut extension project, Egypt, Massoud et al. (1971).

As shown in Fig. 1, the shape of the moisture characteristic curves of these highly calcareous soils is similar to that of sandy soils where there is a marked decrease in the moisture content with increasing tension up to 1.0 atm as compared to that at higher tensions. The same was found by Hassan (1960). This similarity indicates that the moisture may be held to a large extent by weak surface forces. The figure also shows that the soil texture (clay + silt) has a major influence on the moisture retention, whereas CaCO₃ (above 20 percent) has only a minor one.

The effect of CaCO₃ on moisture retention and/or movement seems to be more related to its effect on the formation of different structural units rather than to the ability of its surface to retain water. Consequently, there will be a better understanding of the effect of CaCO₃ on water retention when such studies are carried out on undisturbed samples. However, the statistical analysis of the relation between the moisture retained at 15 atm (FWP) and the silt, clay and clay + silt content in the disturbed samples showed that a high correlation exists between FWP and each of the tested independent variables, especially the clay + silt fraction. In non-calcareous soils we would expect that the moisture retained at 15 atm might be closely correlated with the clay fraction

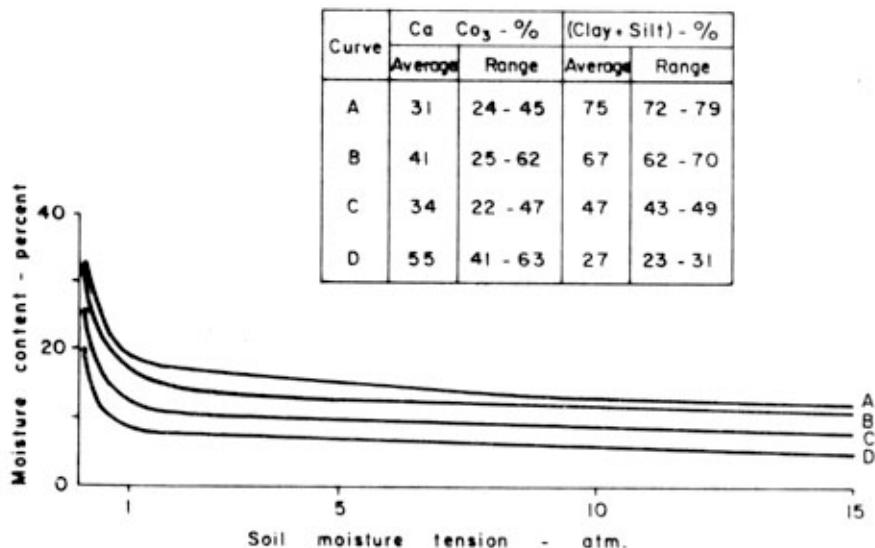


Fig. 1. MOISTURE CHARACTERISTIC CURVES OF HIGHLY CALCAREOUS SOILS

rather than the clay + silt or the silt fractions. But the presence of about 30 percent of the CaCO₃ of these soils in the clay fraction, as shown in Table 2, and coating of the clay particle surfaces by CaCO₃, as proposed by Hassan (1960), relatively decreases its ability to retain moisture.

The ability of the silt fraction to retain moisture by surface active forces is limited and it may take place physically by forces such as surface tension in the minute interpores. Woodruff (1950) mentioned that the cementing effect of CaCO₃ reinforces the capillary walls and this effect increases as the CaCO₃ increases with a subsequent reduction of the inner diameter of the capillary pores. Consequently, the water retained in these capillary pores increases against a certain pressure difference. The close correlation found between the clay + silt fraction and the moisture content retained at 15 atm suggests that water retention in these highly calcareous soils is governed by both surface active forces and physical forces.

It has been found that the average available moisture range between 0.33 and 15 atm values for the three dominant textural classes: sandy loam, loam and clay loam is 8.5, 11.9 and 12.6 percent by weight respectively with corresponding 15 atm values (FWP) of 6.3, 8.6 and 11.6 percent. About 50 and 75 percent of the available moisture is depleted at tensions of 1 and 5 atms respectively, regardless of the soil texture. This suggests that the frequency of irrigation in such soils should be closer than in non-calcareous soils.

6.4. Moisture Regime and Plant Growth

The study of plant response to different moisture regimes is significant not only to crop production but also to the water economy and soil conservation. It has just been pointed out that in highly calcareous soils frequent irrigation could be recommended, as deduced from the moisture characteristic curves. In other words, irrigation at a relatively low moisture tension would be advisable. To check on the reliability of this advice, a study was carried out on the effect of moisture regime on the vegetative growth of maize grown on highly calcareous soils, Massoud *et al.* (1969).

Six sandy loam soils having a different CaCO_3 content (25, 35, 40, 45, 55 and 65 percent) and four soils of different texture (loamy sand, sandy loam, loam and silt loam) but about the same CaCO_3 content (45 percent) were used in the study. The differential irrigation treatments, which started two weeks after planting and lasted for seven weeks, were given at tensions of 0.33, 0.75, 5 and 10 atm, with enough moisture to raise the tension to 0.1 atm.

The effect of moisture regime and CaCO_3 content on stalk height, fresh weight and dry weight of plants grown on the sandy loam soils with different CaCO_3 content was found to be highly significant. As shown in Fig. 2 the increase in growth followed the sequence

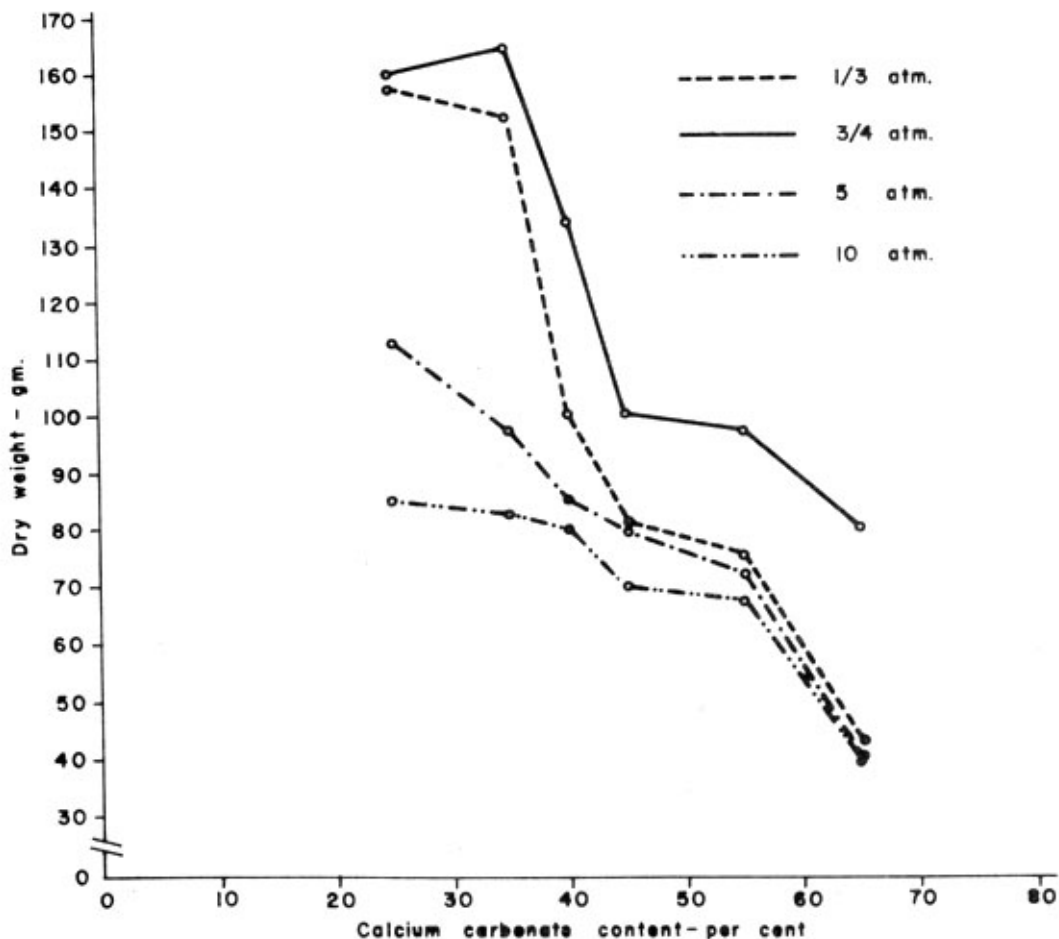


Fig. 2 - Effect of CaCO_3 content on dry weight of plants irrigated at different soil moisture tensions.

of irrigations at tensions of 0.75 > 0.33 > 5 > 10 atm regardless of the CaCO₃ content. These tensions correspond to a depletion of 65, 45, 90 and 95 percent of the available moisture between 0.1 and 15 atm values. Irrigating at 45 percent moisture depletion did not give the same good effect as that at 65 percent, probably due to poor aeration. The figure also shows that there is a possibility of doubling the dry weight of plants by following the right irrigation regime. Under a given moisture regime, it is clear that plant growth was adversely affected by increasing the CaCO₃ content, especially above 35 percent, probably due to nutritional problems.

The response to the different moisture regimes by those plants grown on different textured soils and similar CaCO₃ content also emphasized the high significant effects of moisture regime on growth. Texture was only significant at the 5 percent level. The response to different moisture regimes followed the sequence mentioned above and better growth was obtained following the increase in clay content.

Although the study was carried out in large pots, the response of the vegetative growth to the different moisture regimes generally agreed with that predicted from the moisture tension curves of highly calcareous soils. Similar studies are recommended for different crops under field conditions with special emphasis on yield rather than the vegetative growth of plants.

6.4. Diffusivity

Water movement in a soil profile, as a result of certain processes such as surface irrigation, rainfall or sprinkler irrigation, fluctuations of water table and surface evaporation, is governed by basic flow equations whose solutions conform to the boundary conditions. For vertical flow, the equation of continuity can be simply written as

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left(D \frac{\partial \theta}{\partial z} \right) + \frac{\partial K}{\partial z}$$

- where θ = moisture content on volume basis
 t = time
 z = vertical distance below soil surface
 K = hydraulic conductivity
 D = diffusivity

The diffusivity is a soil property which is uniquely defined when the moisture content is specified, Childs and Collis-George (1950), and can be found from the relation.

$$D = K \left(\frac{\partial \psi}{\partial \theta} \right)$$

- where $\frac{\partial \psi}{\partial \theta}$ = the inverse of the specific water capacity
at a particular value of θ .

Prior to the applications of the flow equation to practical problems, the values of K and D should be known at different tensions and soil moisture contents. Since D is a soil property that reflects the readiness with which soil conducts water, it is rather important to know how this property behaves in calcareous soils.

The relation between diffusivity of water through soil and calcium carbonate content was studied for calcareous and non-calcareous soils of different texture, Salim and Massoud (1966). The calcareous soils are those given in Table 2. The non-calcareous soils are alluvial sandy loam (clay 10 percent, silt 10 percent, sand 80 percent and CaCO_3 1.4 percent) and alluvial sandy clay loam (clay 22 percent, silt 24 percent, sand 54 percent and CaCO_3 1.3 percent). The diffusivity was determined following the procedure described by Crank, (1956). The relation between soil moisture content and diffusivity is given in Table 3.

Table 3 - Soil moisture diffusivity "D" of calcareous and non-calcareous soils at different moisture content "θ"

| Soil No. : | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|--------------------------------------|------------------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| Texture : | Sandy clay loam | | Sandy loam | | Sand | | Sandy loam | Sandy clay loam |
| CaCO_3 -% : | 26 | 46 | 22 | 7 | 38 | 11 | 1.4 | 1.3 |
| θ - cm^3/cm^3 | D - cm^2/min | | | | | | | |
| 0.10 | 7.2×10^{-3} | 1.8×10^{-2} | 6.7×10^{-2} | 7.2×10^{-2} | 1.1×10^{-1} | 4.9×10^{-1} | 5.0×10^{-3} | 1.2×10^{-4} |
| 0.15 | 1.7×10^{-2} | 3.2×10^{-2} | 1.2×10^{-1} | 1.7×10^{-1} | 2.7×10^{-1} | 2.1 | 1.5×10^{-2} | |
| 0.20 | 2.7×10^{-2} | 4.8×10^{-2} | 1.6×10^{-1} | 2.1×10^{-1} | 1.1 | 8.5 | 5.1×10^{-2} | 9.4×10^{-3} |
| 0.25 | 5.4×10^{-2} | 6.3×10^{-2} | 2.6×10^{-1} | 4.7×10^{-1} | 3.3 | 31 | 1.1×10^{-1} | |
| 0.30 | 1.8×10^{-1} | 1.4×10^{-1} | 4.4×10^{-1} | 2.9 | 12.6 | | 2.4×10^{-1} | 5.1×10^{-2} |
| 0.35 | 4.9×10^{-1} | 5.4×10^{-1} | 1.1 | 8.2 | | | 5.7×10^{-1} | |
| 0.40 | 7.8×10^{-1} | 1.3 | 3.1 | | | | 1.5 | 1.6×10^{-1} |
| 0.45 | 2.2 | 2.5 | | | | | 3.1 | 2.6×10^{-1} |
| 0.5 | | 7.3 | | | | | 6.5 | 3.5×10^{-1} |

The results show that for calcareous as well as non-calcareous soils the diffusivity at a given moisture content is higher in sandy > sandy loam > sandy clay loam soils. Comparing calcareous with non-calcareous soils having about the same particle size distribution we observe that the calcareous soils have higher diffusivity. This means that for the same boundary conditions and under the same moisture gradient the water has a better chance of moving faster through calcareous than non-calcareous soils.

As to the effect of the total carbonate content and its size distribution, it may be said that for highly calcareous soils having about the same soil particle and carbonate size distribution (samples 1 and 2), the total carbonate content above 20 percent has a similar effect on diffusivity. It seems that the presence of CaCO_3 in concentrations of

about 10 percent has more effect on increasing diffusivity, especially at high moisture content, than when it is above 20 percent. Also the presence of the carbonate in the clay fraction tends to decrease diffusivity (sample 3 as compared with sample 4).

The effect of CaCO_3 on diffusivity of calcareous soils could be explained on the same basis given for moisture characteristics. It is known that the presence of calcium carbonate helps the formation of stable aggregates, Chiles (1940), and it seems that the pore size distribution of these aggregates varies according to their CaCO_3 content. Within a certain range of CaCO_3 content, probably up to 10 or 15 percent, these aggregates have a relatively large proportion of coarse pores and as the CaCO_3 content increases, say up to 20 or 25 percent, it will precipitate on the inner walls of the capillary tubes with a subsequent increase of the small pores and a relative decrease in diffusivity. The effect of increasing carbonate beyond this range, as is the case in highly calcareous soils, will depend not on the total concentration but on its size distribution. The coarser the size of the carbonate grains the higher the diffusivity would be.

6.5. Infiltration and Redistribution

Infiltration is the downward entry of water into soils as happens during irrigation or rainfall. After the cessation of the irrigation or the removal of surface water, the water continues to move downwards for some time under the influence of water content gradient and the gravitational field with a subsequent alteration in the moisture profile. This process is known as the redistribution of infiltrated water. When the water table is at too great a depth below the soil surface to influence water movement near the surface, the rate of downward movement and redistribution of water also slows down with time until it appears to have ceased. This means that the redistribution of moisture in soil is a slow, continuous process which usually involves further penetration of the water front at the expense of the upper regions. The water content, which exists when this downward movement becomes negligible, is usually known as the field capacity. Thus the moisture content at field capacity is not a state of static equilibrium but should usually be considered in terms of dynamic equilibrium.

The practical aspects of infiltration and redistribution of moisture in soils are of significant importance to irrigation practices and soil and water conservation. If the infiltration rate is less than the rate of water application to the soil surface, ponding or runoff will occur depending on the slope of the surface and its configuration. Time and soil properties such as diffusivity, hydraulic conductivity and initial moisture content affect these processes. So, the presence of a surface crust, or a relatively impervious layer within the profile, controls these processes. In calcareous soils where the formation of crust and hardpan is to be expected, the infiltration rate would be less than in a normal uniform soil, Hillel and Gardner (1970). It is through soil management practices, such as proper tillage and addition of organic matter, that the infiltration rate can be improved. For efficient irrigation one has to account for water redistribution in the soil profile. Depending on the effective rooting depth of the irrigated crops, the amount of irrigation water should replenish the soil reservoir after its redistribution to that depth. Under rainfed farming the amount of rainfall stored in the soil profile and its redistribution pattern are among the main factors that determine the rooting characteristics and the yield of the crop.

The moisture profile during infiltration can be computed from the solution, given by Philip (1957), of the continuity equation mentioned before, when the diffusivity and conductivity are known. In a study by Soliman (1968) on infiltration and redistribution of water in a highly calcareous sandy soil (clay 3 percent, silt 10 percent, sand 87 percent and CaCO_3 33 percent) the agreement between the experimental and calculated moisture profiles was found to be good as shown in Fig. 3. In other words the solution given by Philip adequately predicted the shape of the wetting front and depth of penetration.

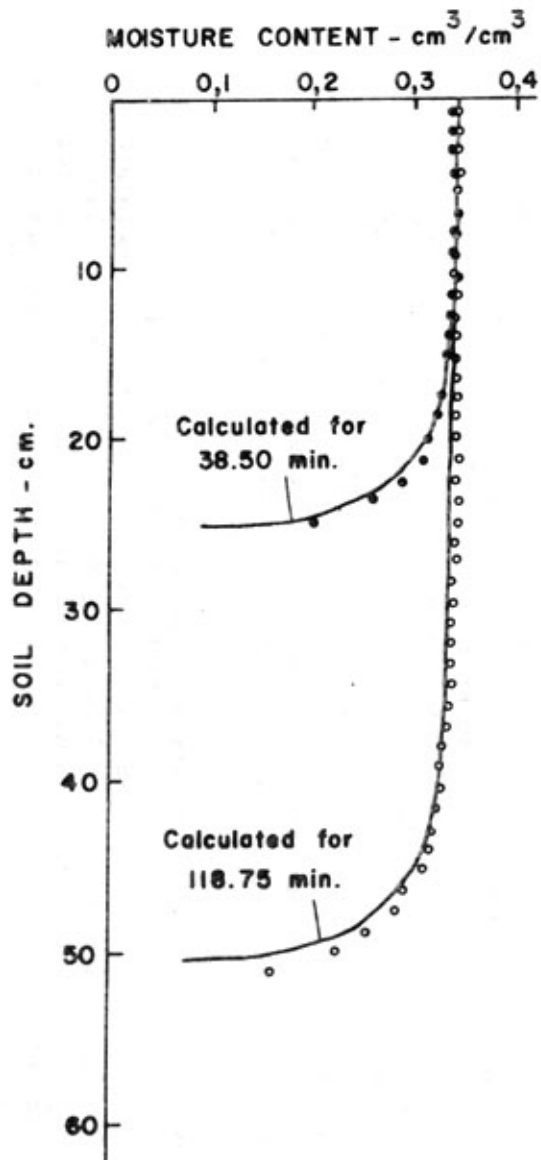


Fig.3 Measured and calculated soil moisture profiles of air dry calcareous soil for vertical movement.

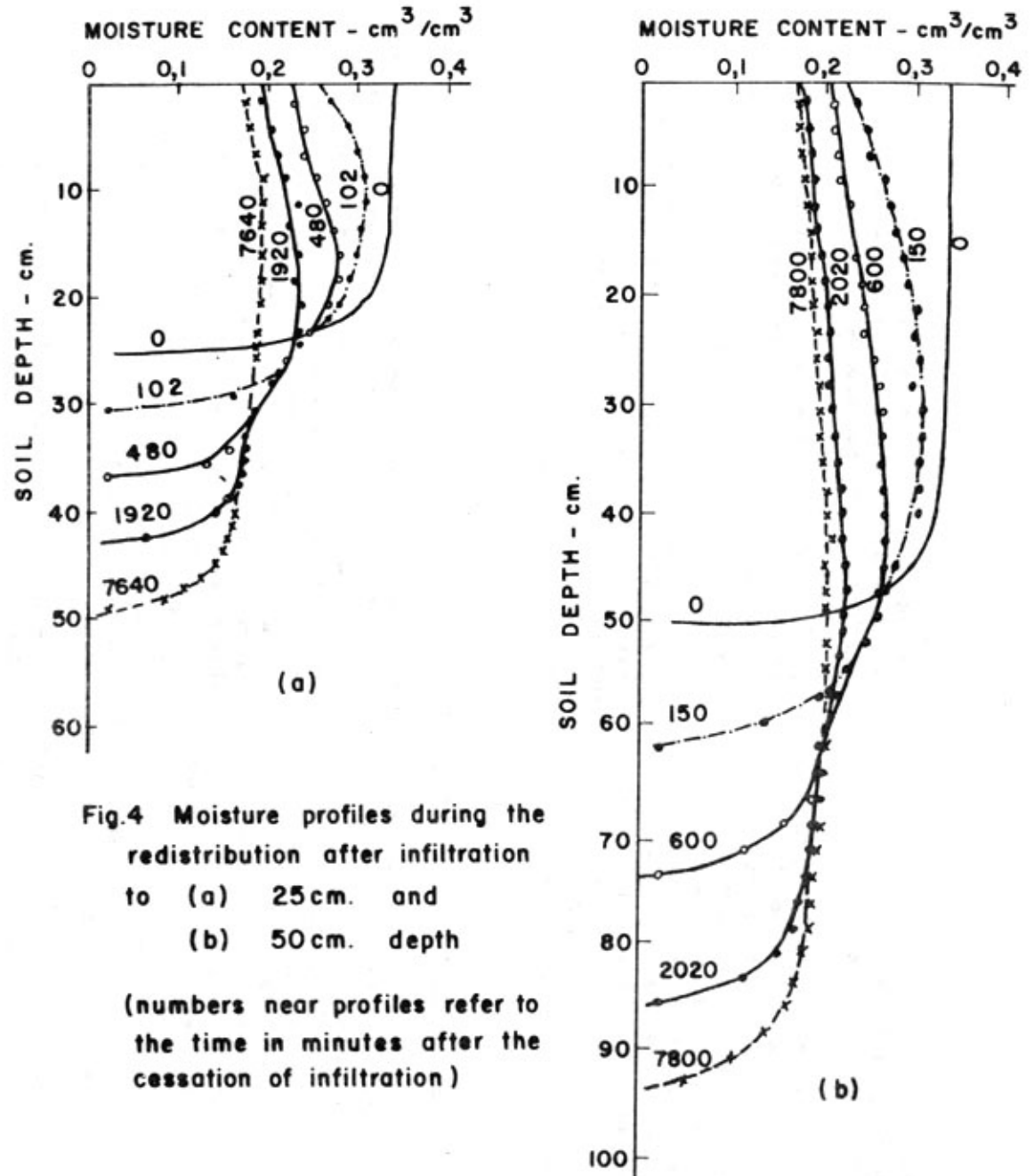


Fig.4 Moisture profiles during the redistribution after infiltration to (a) 25 cm. and (b) 50 cm. depth

(numbers near profiles refer to the time in minutes after the cessation of infiltration)

For the same soil, the development of the moisture profile during redistribution after infiltration of 8.2 and 16.7 cm of water to corresponding depths of 25 and 50 cm is given in Fig. 4. It is clear that redistribution has proceeded at a fast rate after cessation of infiltration due to existence of moisture gradient and high "D" and "K" values. But as time elapses and the moisture content decreases, with a consequent sharp decrease of "D" and "K", the rate becomes much slower. Although the figure indicates that a true equilibrium cannot be achieved and some movement is always found, one could consider the moisture content of the moisture profile attained at the end of about 1.5 days after the cessation of infiltration as the so-called field capacity.

Under practical field conditions, the development of such ideal moisture profiles would be affected by the soil structure, stratification, surface evaporation, root extraction and ground water contribution. Therefore, it is advisable to run field tests for infiltration and development of moisture profiles during redistribution in order to have a true picture of the water storage capacity of the soil.

6.6. Soil Crusting and the Moisture Regime

Soil crusting can be considered as one of the main problems of the newly reclaimed calcareous soils. Crusts do not only affect infiltration and soil aeration but also the emergence of seedlings. Carnes (1934) reported that the amount of crust formed on a soil depends on the amount of rain and that the slower the drying rate the harder the crust whose strength bears an inverse relationship to its moisture content at time of breaking. Isiumov (1940) indicated that crust formation is influenced by a heavy mechanical composition of soil combined with temporary excessive moisture. Lemos and Lutz (1957) have demonstrated the influence of many factors on crust strength. Increasing silt or the fraction less than 0.1 mm, 2:1 type clay mineral, compaction by rainfall and soil puddling, increase crust strength while successive cycles of wetting and drying decrease it.

In a study on the effect of moisture regime on crust formation in highly calcareous soils, Massoud *et al.* (1968), it was observed that in a silt loam soil (clay 7 percent, silt 65 percent, sand 28 percent and CaCO_3 43 percent) soil crusting was more obvious than in a loam or a clay soil. To the silt loam soil packed in pots, six water levels (0.3 F.C. - 5 F.C.) were applied to the surface except for the lowest treatment where water was sprinkled from a 1.5 metre height. The time at which cracking started to develop and crusts were formed and could be easily separated from the sub-crusts was recorded. Twenty-five days after the water application, samples were taken from the crust and sub-crust for the determination of moisture content, bulk density, salinity, CaCO_3 content and mechanical analysis. This procedure and analysis was repeated for four wetting and drying cycles. The significant results are given in Table 4.

The results indicate that heavy water applications delayed cracking and crusting while very light applications and successive wetting and drying enhanced their formation. It has been observed that the thickness of the crust increased five-fold by increasing the water application from 0.3 to 5 F.C. The most significant difference between the crust and sub-crust was the increase in the bulk density of the crust relative to the soil beneath it, which is in agreement with the results obtained by Hillel (1960). The EC_e was also higher in the crust but the differences became less as the water application successively increased.

The mechanism of crust formation in calcareous soils seems to follow a sequence of processes involving slacking and breakdown of aggregates, segregation, solution of $\text{Ca}(\text{HCO}_3)_2$, rearrangement of particles and redeposition and cementing by CaCO_3 on desiccation. In the light of this sequence the highly calcareous silt loam soil, which might be expected to form a consolidated aggregate when dry, becomes soft and friable

Table 4 - Effect of moisture regime on time of cracking and crusting and bulk density (gm/cm^3) of a highly calcareous silt loam soil

| Water Application | First Cycle | | | | Fourth Cycle | | | |
|-------------------|-------------|----------|--------------|-----------|--------------|----------|--------------|-----------|
| | Cracking | Crusting | Bulk density | | Cracking | Crusting | Bulk density | |
| | days | days | crust | sub crust | days | days | crust | sub crust |
| 0.3 F.C. | 1 | 1 | 1.60 | 1.30 | 1 | 3 | 1.60 | 1.30 |
| F.C. | 1 | 14 | 1.60 | 1.20 | 1 | 11 | 1.78 | 1.36 |
| 2 F.C. | 1 | 16 | 1.66 | 1.20 | 1 | 13 | 1.78 | 1.39 |
| 3 F.C. | - | 19 | 1.69 | 1.27 | 2 | 14 | 1.80 | 1.40 |
| 4 F.C. | - | 20 | 1.69 | 1.30 | 2 | 15 | 1.82 | 1.41 |
| 5 F.C. | - | 24 | 1.71 | 1.32 | 2 | 17 | 1.85 | 1.45 |

when wet and breaks easily in the presence of water and by the impact of sprinkled water drops. Following this destruction of the aggregates and the dispersion of the particles some segregation between different sizes would occur, especially in the surface soil and, consequently, a closer packing of the soil particles which increases the bulk density of the crust. The formation of a relatively massive crust in soils receiving heavy water applications is related to the fact that the rate of drying is slower than in those receiving lighter applications and the drying of the latter is helped by the presence of cracks.

From the practical point of view where soil crusting occurs, the frequency of irrigation should be close enough to prevent drying of the soil surface and hardening of the crust, especially under heavy water application.

6.7. Soil Crusting and Seedling Emergence

Extensive work has been done on the nature and properties of soil crust and its relation to the emergence of various seeds. Hanks (1960) cited references indicating that seedling emergence may be limited by insufficient oxygen diffusion at the seed depth, limited moisture or high mechanical strength of surface crust. He showed that seedling emergence will be limited when the soil dries because of the increase in crust strength and the decrease in the ability of the seedling to emerge at a given crust strength. Parker and Taylor (1965) found that the soil moisture tension, planting depth and plant species affected grain sorghum emergence at specified soil strength. Taylor et al. (1966) studied the relation between soil strength as measured with a penetrometer and the emergence of corn, onions, barley, wheat, switch grass and rye seedlings. They found that the percentage of the tested gramineae which emerged slightly decreased as crust strength increased to the range of 6 to 9 bars and no emergence occurred above the range of 12 to 18 bars while emergence of onion was prohibited at 2 bars.

The effect of soil crusting on wheat seedling emergence was studied in highly calcareous soils by Massoud et al. (1968) where factors such as moisture tension, texture, carbonate content and thickness of the crust were investigated. Four soils (Group I)

with about 45 percent CaCO_3 and different texture (loamy sand, sandy loam, loam and silt loam) and another four sandy loam soils (Group II) with varying CaCO_3 content (25, 35, 40 and 45) were packed to a bulk density of 1.3 gm cm^3 in short brass cylinders 2, 2.5, 3 and 4 cm high and 7 cm in diameter. The moisture content of the saturated soil columns was brought to equilibrium at tensions of 0.1, 0.33, 0.4, 0.5 and 0.6 atm. Germinated wheat seeds placed on top of the 2.5 cm columns were covered with the 2, 3 and 4 cm columns, gently pressed to ensure good contact and thus behave like soil crusts of known moisture tension at the time of seedling emergence. Seedling emergence was recorded daily for 10 days as well as the length of each seedling. The moisture content of the top columns (crusts) and lower columns (sub-crusts) was determined at the end of the experiment.

The results showed that the moisture tension of the crust at the time of emergence has a highly significant effect on the initial and ultimate time of emergence, Fig. 5, as well as the ultimate number of emerging seedlings, Fig. 6. Increasing soil moisture tension of the crust delayed emergence and decreased it especially between 0.33 and 0.4 atm. The length of the seedlings was highly affected by the soil moisture tension. The average weighted means of seedling length on the 10th day were 18, 16, 6, 8 and 6 cm where the initial moisture tensions of the crust were 0.1, 0.33, 0.4, 0.5 and 0.6 atm respectively.

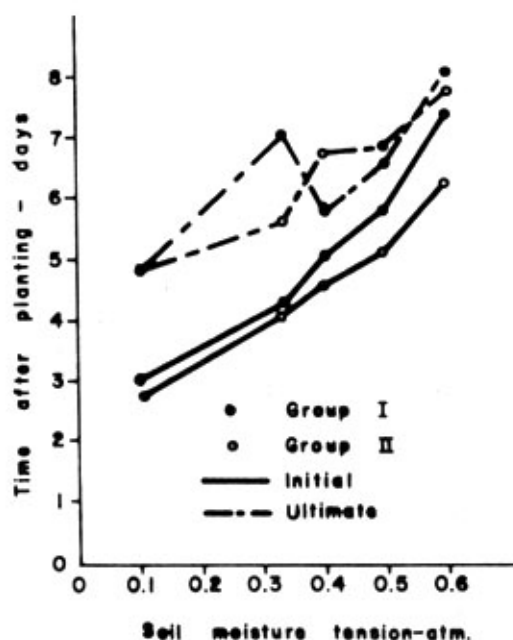


Fig. 5- Relation between initial moisture tension of crust and time of emergence.

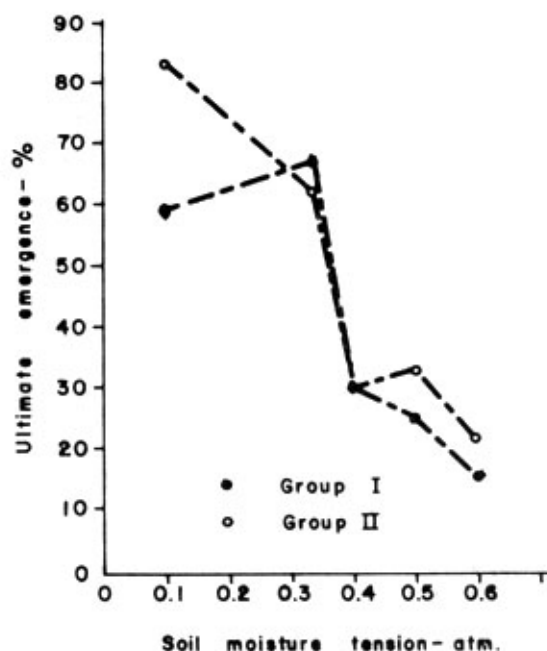


Fig. 6- Effect of initial moisture tension of crust on ultimate emergence.

Apart from the effect of soil moisture tension on seedling emergence and growth, it also affected the crust strength. From the known initial and final moisture contents of the crust, it was possible to estimate its average rate of drying which became slower as its moisture tension increased above 0.33 atm and consequently the crust became harder.

The thickness of the crust was found to affect the rate of emergence as well as its ultimate percentage. Doubling the thickness of the crust delayed emergence by two days but reduced it by about 35 to 50 percent.

The effect of the crust texture was significant only on the ultimate percentage of emerging seedlings which was highly correlated with the clay content ($r = -0.99$) followed by silt + clay ($r = -0.74$) and finally with silt ($r = -0.63$). Further statistical analysis showed that the moisture content at a given tension was positively correlated with clay and silt + clay which should help increasing emergence. Since this was not the case, it could be suggested that increasing the clay content led to an increase in the crust strength as found by Hanks (1960).

The effect of the CaCO_3 content of the crust was slight on rate of emergence but significant on the percentage of ultimate emergence. Moreover, the average ultimate percentage of emergence with respect to CaCO_3 content was relatively low, being 41, 51, 45 and 47 for crusts having CaCO_3 of 25, 35, 40 and 50 percent respectively. It seems that the effect of CaCO_3 on crust strength and wheat seedling emergence became detrimental at a level below 25 percent especially if coupled with high moisture tension and deep seeding.

From the practical point of view, the study recommended that in order to have a good wheat stand in highly calcareous soils, the moisture tension of the crust during emergence should be kept low (below about 0.33 atm) and that planting depth be relatively shallow (less than 4 cm). Since in heavier textured soils the crust tends to be harder, the amount of seeds needed for planting may also be increased.

It could also be possible through some other planting techniques to overcome the hazardous effects of soil crusting on seedling emergence. Such techniques should be tried for various crops. In a study on maize seedling emergence in highly calcareous sandy loam soil (CaCO_3 28 percent) by Massoud *et al.* (1969) the effects of moisture content at the time of planting, planting method (furrow versus surface), planting site, irrigation (heavy versus light) and number of seeds per hill were investigated under field conditions.

The effect of moisture content was studied under furrow and surface planting. Different moisture levels at the time of planting were achieved by planting just before irrigation, 1, 2, 3, 4 and 5 days after in the case of furrow planting, and before irrigation, 2, 4, 6, 8 and 10 days after in the case of surface planting. The results given in Table 5 indicate the significant effects of the moisture content on maize seedling emergence and that the highest emergence was achieved when seeds were irrigated right after sowing regardless of the planting method.

Table 5 - Ultimate maize seedling emergence as affected by soil moisture content and planting technique

| Treatment ^{1/} | Furrow planting | | | Surface planting | | |
|-------------------------|-----------------------|--------------------------------------|--------------------------------------|-----------------------|--------------------------------------|--------------------------------------|
| | Days after irrigation | P _w at time of planting % | Ultimate emergence after 10 days - % | Days after irrigation | P _w at time of planting % | Ultimate emergence after 10 days - % |
| A | 0 | 22.5 | 92.3 | 0 | 23.5 | 95.0 |
| B | 1 | 16.1 | 36.4 | 2 | 14.7 | 33.0 |
| C | 2 | 12.5 | 41.7 | 4 | 11.7 | 49.2 |
| D | 3 | 11.3 | 67.3 | 6 | 9.4 | 59.2 |
| E | 4 | 8.4 | 65.2 | 8 | 8.2 | 54.8 |
| F | 5 | 7.9 | 54.2 | 10 | 6.2 | 39.7 |

^{1/} In treatments B and C seeds were covered by puddled soil; in D, E and F seeds were covered by broken crust.

Planting the seeds in a wet soil means they will be covered by a puddled soil which reduces emergence as a result of forming a hard crust upon drying, as found by Lemos and Lutz (1957). Breaking the crust improved emergence. Generally, the moisture content, soil puddling and breaking of the crust had more pronounced effects on emergence of maize seedlings than the planting method.

Under furrow planting, the site of sowing was found to have a significant effect on emergence whether light or heavy irrigations were applied right after sowing. The ultimate emergence ten days after planting seeds on top, in the upper third and lower third of the ridge was 54, 80 and 94 percent with heavy irrigation and 44, 69 and 91 percent with light irrigation respectively. Since the moisture content at the planting sites was initially about the same, the reduction in emergence could probably be attributed to the higher soil dryness and the increased crust strength of the top and upper third of the ridge in relation to the lower third, especially in the case of light irrigation.

Regarding the effect of number of seeds per hill on emergence, the result showed that planting of 1, 2, 3, 4 and 5 seeds per hill gave ultimate emergence of 70, 89, 90, 92 and 95 percent respectively. The rather insignificant effect due to increasing the number of seeds from 2 to 5 is due to the fact that maize seedlings, like wheat, worm their way through the crust and do not push on it as is the case with cotton seeds and other dicotyledons.

6.8. Crust Strength

Strength is one of the important properties of soil, not only in relation to plant production but also to construction works. Various methods have been used to measure soil strength and to find out how it is affected by other soil properties. Proctor (1933) developed the soil plasticity needle and found that a curve relating the resistance to penetration with the moisture content could be developed. Henin (1936) used a penetrometer to obtain an index of tilth. Richards (1941) described an expensive penetrometer and showed that seedlings were affected by the presence of plant roots, soil moisture and a compacted layer in the soil. Show *et al.* (1942) found a very rapid increase in resistance (as measured by a penetrometer) with decreasing moisture. The modulus of rupture has been used as an index of crusting by Richards (1953), Allison (1956), Lemos and Lutz (1957) and Hanks (1960). Taylor and Gardner (1963) used waxes as a substratum in root penetration studies measured by ASTM penetrometer. Taylor *et al.* (1966) used a force gauge as a static penetrometer to determine the strengths of the upper surface and concluded that soil strength and not the bulk density should be considered as the critical impedance factor controlling root penetration.

Factors affecting crust strength of highly calcareous soils were studied by Massoud *et al.* (1968). The effects of moisture tension, bulk density particle size and CaCO_3 content were investigated on twenty-seven samples varying in texture from sand to clay and in CaCO_3 content from 18 to 68 percent. Soil packed to specified bulk densities in short columns 4 cm high and 7.5 cm in diameter and equilibrated to the desired moisture tension were considered as simulating crusts of known bulk densities and moisture tensions. Using the ASTM-D 5 Penetrometer, the penetration distance expressed in 0.1 mm and referred to as the penetration number (P.N.) was taken as an index to crust strength; the higher the P.N. the lower the strength.

The effect of moisture tension at 0.15, 0.25, 0.35, 0.5, 0.75 and 1.0 atm on penetrability was studied in sandy clay loam (bulk density 1.30 gm/cm^3) and sandy soils (bulk density 1.55 gm/cm^3). The results are shown in Fig. 7. Increasing the moisture tension reduced penetrability, especially below 0.5 atm. Recalling the moisture characteristics of these highly calcareous soils, where most of the water is depleted at low

tension, closer arrangements of the soil particles and more coherence between them will take place and, consequently the crust strength will increase. Higher penetrability of the sandy soil is probably due to the larger percentage of coarse pores and to its lower ability to shrink and rearrange in closer packing upon drying.

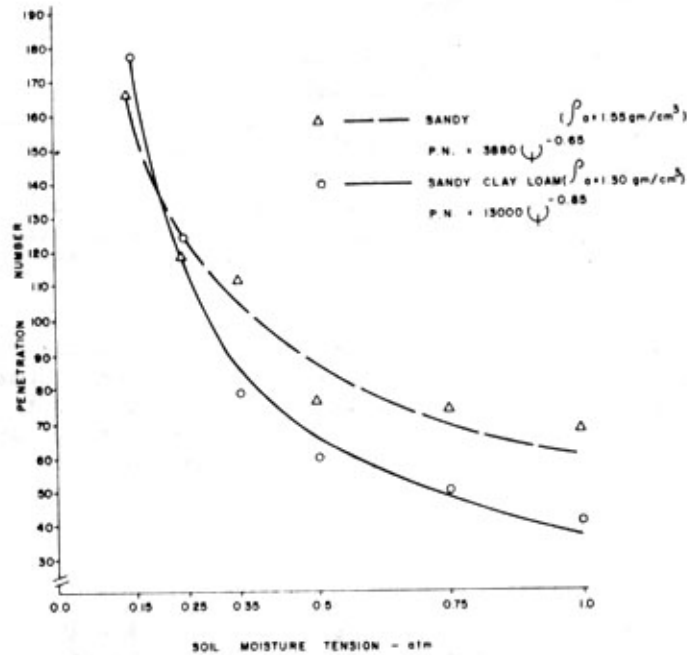


FIG 7 EFFECT OF SOIL MOISTURE TENSION ON PENETRATION NUMBER

The effect of bulk density was investigated using sandy clay loam and sandy soils at three moisture tension levels. The results are given in Fig. 8. at a given soil moisture, penetrability decreased when there was an increase in the bulk density due to closer packing. For soils having the same moisture tension and bulk density (1.7 gm/cm^3), it was found that the lighter the soil the higher the penetrability, which reflects the importance of particle and pore size distribution.

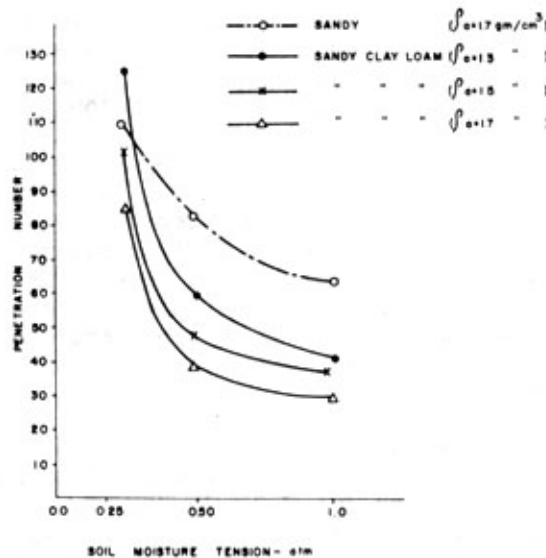


FIG 8 PENETRATION NUMBER AS RELATED TO SOIL BULK DENSITY AT THREE MOISTURE TENSION LEVELS.

To investigate the role of high CaCO_3 content in crust strength, penetrability was measured in all the samples at tensions of 0.25, 0.50 and 1.0 atm and a bulk density of 1.3 gm/cm^3 . The following linear relationships between CaCO_3 content and P.N. were obtained,

$$\begin{array}{llll} \text{P.N.} & = & 151 & - 0.92 & \text{CaCO}_3 & \text{at } 0.25 \text{ atm} \\ \text{P.N.} & = & 69 & - 0.16 & \text{CaCO}_3 & \text{at } 0.50 \text{ atm} \\ \text{P.N.} & = & 45 & - 0.006 & \text{CaCO}_3 & \text{at } 1.0 \text{ atm} \end{array}$$

The effect of increasing CaCO_3 above 18 percent on reducing penetrability became less obvious as the crust became drier and was almost nil at a tension of 1.0 atm. In other words, the cohesive forces between soil particles at relatively high tensions became so strong that the effect of increasing CaCO_3 became less obvious.

The relation between clay, silt and sand content of the soil crust and its strength was obtained from the previous measurements. The results generally show that the penetrability decreased with increasing clay and silt contents but the sand had a positive correlation. Fig. 9 gives the relation between the silt content (50 - 20 microns) and the penetration number.

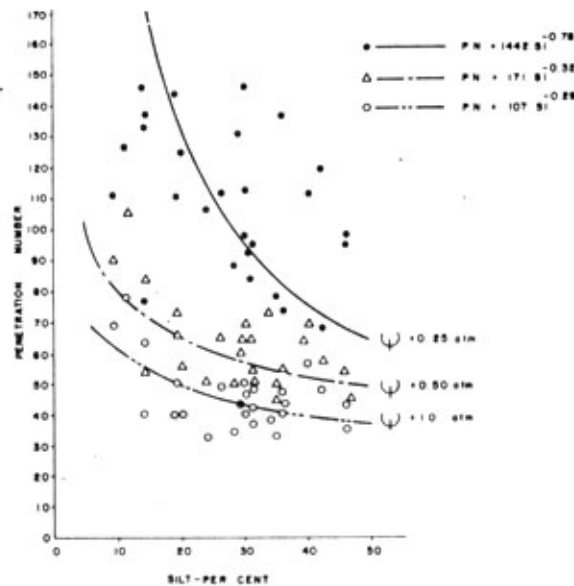


FIG. 9 EFFECT OF SILT CONTENT ON PENETRATION NUMBER AT THREE SOIL MOISTURE TENSION LEVELS

The silt had a more pronounced effect on crust strength than the clay especially at low tensions. In the case of clay sliding the penetrometer needle through the crust might be easier as the moisture content increases by having more clay, but the increase in mechanical impedance tends to oppose the moisture effect. In the case of silt, the mechanical impedance was more effective than that of the moisture content.

To evaluate the relative importance of each of the studied factors on penetrability, statistical analysis was applied to the data obtained at a tension of 0.5 atm. The estimated coefficients and the corresponding t-values are given in Table 6.

Table 6 - Estimated coefficients and corresponding t-values

| Item | Coefficient | Calculated t-value for the exponent ^{1/} |
|-----------------------|-------------|---|
| Bulk density | - 1.539 | 74.8 |
| Soil moisture tension | - 0.853 | 14.4 |
| Silt | - 0.317 | 27.2 |
| Silt + Clay | - 0.309 | 27.4 |
| Sand | + 0.287 | 26.8 |
| Clay | - 0.219 | 31.9 |
| CaCO ₃ | - 0.155 | 10.9 |

^{1/} Significant at the probability level 0.01.

It is clear that all the estimated coefficients are statistically highly significant. Since the exponent coefficients represent the elasticities of the estimated functions, they can be used to evaluate the relative importance of each of the studied factors. It is clear that all the factors, except sand, inversely affect penetrability of the highly calcareous soils. Their relative importance follow the sequence bulk density > moisture tension > silt > silt + clay > sand > clay > CaCO₃.

6.9. Soil Tilth

Tilth is commonly defined as the physical condition of the soil in its relation to plant growth. Adequate aeration, ready infiltration of irrigation water and rainfall and sufficient moisture storage are important functions of good tilth. All tillage operations should aim at the creation and maintenance of good tilth. However, different tilth may be obtained depending on the tillage operations and the physical conditions of the soil at the time of tillage. In highly calcareous soils where crusting and formation of hardpans can be expected special consideration should be given to tillage. The selection of the right plough type, tillage sequence, ploughing depth and moisture content at the time of ploughing should provide good soil tilth.

In a study by Massoud *et al.* (1968), the effect of different tillage implements and techniques on tilth of highly calcareous soils was investigated. Three sets of experiments were carried out in an area of about 35 acres of a sandy loam soil with 35 percent CaCO₃. The lowest value of the soil bulk density and the highest average infiltration rate (for a period of one hour) were taken as indices to good tilth. In the first experiment, the effect of the tillage implements and the sequence of tillage operations was studied at an average moisture content of 7.8 percent within an average ploughing depth of 20 cm. The bulk density was determined for a volume of 1 x 1 x 0.2 m³, while for the infiltration rate the measurements were taken from a basin 1 x 1 m². The results are given in Table 7 in descending sequence of their preference.

In the second experiment, the effect of ploughing depth at an average moisture content of 7 percent was studied using a mouldboard followed by a chisel plough in a perpendicular direction. The results are given in Table 8 in descending sequence of their preference.

The effect of soil moisture on tilth was studied using a mouldboard followed by a chisel plough and a ploughing depth of 25 cm. The results are given in Table 8.

From the results of the study, it is obvious that the infiltration rate, as an index to soil tilth, is more sensitive to tillage operations and techniques than the bulk density. The infiltration rate may vary up to fourfold by a change in the tillage implement and sequence. The selection of the right depth of ploughing and moisture content at the time of ploughing could raise the infiltration rate by 60 to 70 percent.

The study recommended the use of the mouldboard followed by the chisel plough in a perpendicular path with a ploughing depth of 25 cm at an optimum moisture content of about 7.8 percent.

Table 7 - Effect of tillage implements and sequence of tillage operation on bulk density and infiltration rate

| Tillage implements and sequence of operations | | Average bulk density gm/cm ³ | Average infiltration rate. cm/hr |
|---|---|--|-------------------------------------|
| First path | Second path in perpendicular direction to the first | | |
| Mouldboard | Chisel | 0.97 | 15.4 |
| Mouldboard | Heavy duty disc harrow | 1.08 | 11.4 |
| Lister | Chisel | 1.12 | 10.5 |
| Chisel | Chisel | 1.15 | 9.9 |
| Lister | Heavy duty disc harrow | 1.18 | 9.3 |
| Mouldboard & disk spike | | 1.34 | 3.7 |
| Roller & Sowing harrow | | | |
| Unplowed soil | | 1.50 | 3.4 |

Table 8 - Effect of tillage depth and moisture content on bulk density and infiltration rate

| Flowing depth cm | Bulk density gm/cm ³ | Infiltration rate cm/hr | Moisture content % | Bulk density gm/cm ³ | Infiltration rate cm/hr |
|---------------------|------------------------------------|----------------------------|-----------------------|------------------------------------|----------------------------|
| 25 | 0.97 | 15.4 | 7.8 | 0.94 | 16.9 |
| 30 | 1.03 | 12.6 | 6.9 | 1.03 | 12.6 |
| 20 | 1.07 | 11.4 | 9.0 | 1.07 | 11.6 |
| 33 | 1.10 | 10.7 | 9.2 | 1.10 | 10.6 |
| 15 | 1.17 | 9.7 | 6.0 | 1.16 | 9.9 |

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SUMMARY

Soil and water management practices for calcareous soils encompass a wide range of interests, from the microscopic flow of water in fine pores to the overall hydrologic and water quality assessment of entire river basins. This paper reviews some recent research on the application of soil-water flow theory to field situations, trends in irrigation practices and scheduling in the southwestern United States, and advances in river basin salinity control.

The application of soil-water flow theory to field situations requires assumptions and simplifications in the exact theory to allow for the non-homogeneities of a field soil. Approximate solutions have been developed to predict soil profile infiltration and drainage. Leaching of salts from the root zone requires less water for the same amount of salt removed if the soil is maintained unsaturated.

Some soils require minimum tillage to maintain infiltration rates high enough for adequate leaching of salts. Some tillage practices are designed to minimize accumulation of salts and to provide adequate moisture to germinating seeds. A trend in irrigation practices is toward "dead level" basins, ranging from 2 to 16 hectares. Dead level basins are very efficient from the point of view of water application efficiency and salt control. Consumptive use data for specific crops and computer forecasting are now used for irrigation scheduling.

1/ Contribution from the Soil, Water, and Air Sciences, Western Region, Agricultural Research Service, U.S. Department of Agriculture.

7.1. Introduction

Soils that have weathered under arid climatic conditions are characterized by an accumulation of calcium carbonate at some point in the profile. This accumulation may be rather concentrated in a narrow zone or more dispersed, depending upon the quantity and frequency of rainfall, topography, soil texture and vegetation. In some soils the calcium carbonate deposits are concentrated into layers that may be very hard and impermeable to water. These caliche layers are formed by rainfall (at nearly constant annual rates) leaching the salts to a particular depth in the soil at which the water content is so low that the carbonates precipitate. They are also formed by salts moving upward from a water table (caused by irrigation) and precipitating near the top of the capillary fringe. Caliche layers are only one of many factors to be considered in a soil and water management programme for calcareous soils.

A major characteristic of calcareous soils is that they develop in regions of low rainfall and must be irrigated to be productive. Frequently, the irrigation water is the cause of many management problems. Almost all waters used for irrigation contain inorganic salts in solution. These salts may accumulate within the soil profile to such concentrations that they modify the soil structure, decrease the soil permeability to water, and seriously injure growing plants.

In managing calcareous soils, two major objectives are to provide optimum water for plant growth without waste and to control salts. The two objectives are essentially contradictory, in that a water management practice that provides optimum water with no wastage may allow salts to accumulate and a practice to control salts requires water in excess of that required for optimum plant growth. Obviously, practical experience and a knowledge of basic principles are required for a successful soil and water management programme.

Often managers must look beyond an individual farm and be concerned with an irrigation district and even an entire river basin. Irrigation waters diverted at downstream locations contain salts leached from soils upstream and returned to the river through drainage channels and by underground flow. Agricultural communities are becoming more concerned with the return flow of irrigation waters to rivers and groundwater basins. In addition to the natural soluble salts in the drainage water, fertilizers and pesticides applied to the soil appear in the return flow and may present a hazard to downstream municipal users of the water. Thus, a comprehensive soil and water management programme must encompass a wide range of interests, from the microscopic flow of water in very fine pores to the overall hydrologic and salinity assessment of entire river basins.

This paper presents a brief review of some basic principles and some practical methods of soil and water management for calcareous soils in the southwestern United States. Much of the information is readily applicable to other regions in which calcareous soils are irrigated.

7.2. Basic Principles

Managing calcareous soils for optimum crop production requires a mixture of practical experience and scientific knowledge. Some areas have been in production for centuries with the farmer or manager relying solely on practical knowledge passed to him by ancestors and obtained from his own experience. Soil and water science is relatively new, beginning a little over a century ago, with the main impetus occurring during the past three decades. A tremendous amount of information has been obtained concerning soil physical and chemical properties, water movement through soil, water quality, salt reactions in water and soil, water management and irrigation requirements. Yet, not all of this basic information has been applied to improve management practices. Two possible reasons for this lack of application are: (a) insufficient information

for bridging the gap from experiment to application, and (b) the natural reluctance of some managers to incorporate untested ideas in their management programme. In the following sections we will review some basic principles and, where possible, indicate the status of current research and point out areas where future research may be needed.

7.2.1. Water movement

Soil and water management practices are influenced by the rate at which soil will conduct water. Irrigation scheduling, salinity control practices and drainage design are examples of practices that are determined by the rate of movement of soil water. Soil water flow theory is based upon the equation (in one dimension)

$$\partial \theta / \partial t = \partial (K \partial H / \partial z) / \partial z \quad (1)$$

where θ is the volumetric water content, t the time, K the hydraulic conductivity, H the hydraulic head, and z the vertical distance below the soil surface. An alternate form of equation (1) is

$$\partial \theta / \partial t = \partial (D \partial \theta / \partial z) / \partial z + \partial K / \partial z \quad (2)$$

where $D = K h / \partial \theta$ is the soil water diffusivity, and h is the soil-water pressure head. The transfer parameters K and D always appear in solutions to equations (1) and (2). Methods for measuring K and D have been reviewed by Klute (1972) and by Bouwer and Jackson (1972).

Both K and D are strongly dependent on water content and pressure head. Thus solutions of equations (1) or (2) are difficult to obtain. Computers are frequently used to obtain numerical solutions to the equations. Another complication is that the relation between θ and h is assumed to be unique, whereas it is hysteretic.

The heterogeneity of field soils limits the applicability of equations (1) and (2). The coefficients K and D may vary widely both horizontally and vertically within a field. Nevertheless, some approximate solutions of the equations have been successfully applied to field situations (Nielsen *et al.* 1972). For example, Black *et al.* (1969) integrated equation (1) from the soil surface to depth L . By assuming that a unit hydraulic gradient prevails and that no evaporation occurs at the surface during drainage, they obtained

$$L d\bar{\theta} / dt = -K \quad \text{at } z = L \quad (3)$$

where $\bar{\theta}$ is the average water content in the profile from 0 to L . Davidson *et al.* (1969) measured K in the field at several depth intervals and, for a silty clay soil, approximated the conductivity-water content relation with the expression

$$K = K_s \exp[\alpha(\theta - \theta_s)] \quad (4)$$

where α is a constant and the subscript s refers to the saturated condition.

Substituting equation (4) into (3) and integrating yields the average water content for the profile as a function of time. Differentiating that result with respect to t yields

$$q = K_g / (1 + \alpha K_g t / L) \quad (5)$$

which gives the flux q at the depth L as a function of time. Fig. 1 shows the measured and calculated flux at the 152 cm depth for Miller silty clay as a function of time. The agreement between measured and calculated is quite good, when the simplifying mathematical assumptions and the variability of field soils are considered.

Information predicted by equation (5) and shown in Fig. 1 is useful for predicting the amount of water that would move out of the root zone. Such information aids in estimating the quantity of irrigation water required for leaching or for maximum efficiency of irrigation.

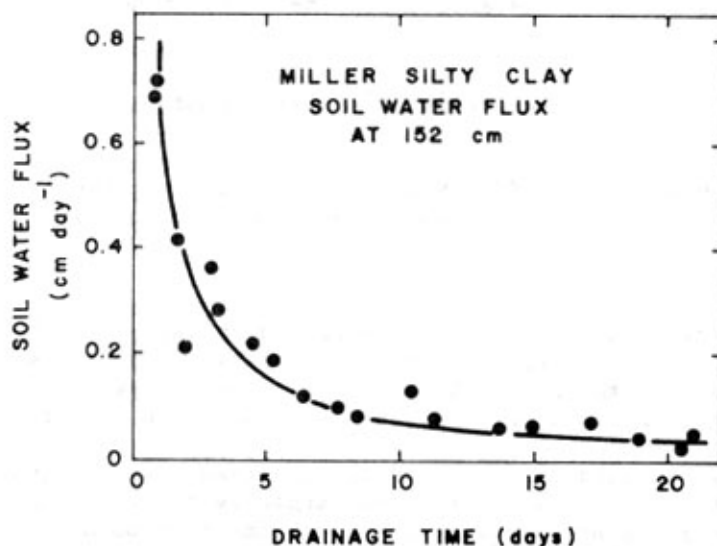


Figure 1. Measured and theoretical soil water flux at 152 cm in Miller silty clay following a heavy irrigation (Davidson *et al.* 1969).

Philip (1957) solved equation (2) for the infiltration of water into soils. The solution was in the form of an infinite series in which, for short times, only the first two terms are important. The resulting expression is

$$I = S t^{1/2} + A t \quad (6)$$

where I is the accumulative infiltration in time t . The sorptivity (S) is essentially a measure of the capacity of the medium to absorb or desorb liquid by capillarity. The term A is approximately equal to two-thirds of the saturated conductivity (K_g).

The infiltration rate (i) is obtained from (6) by differentiation, that is,

$$i = (1/2) St^{-1/2} + A \quad (7)$$

Equation (7) indicates that the infiltration rate will be high for a short time, then decrease rapidly with time and approach a constant. This behaviour is well known from field experience. When the infiltration rate approaches a constant, it is known as the "final" infiltration rate.

In addition to theoretical equations, a host of empirical equations have been proposed to predict infiltration rates. Whisler and Bouwer (1970) compared several equations, including equation (7). They stated that equation (7) gave useful results if S and A were evaluated statistically from measurements of infiltration. Watson (1959) found that equation (7) represented field infiltration rates particularly well for short times.

Field evaluation of infiltration rates in calcareous soils may be complicated by caliche layers or by hardpans formed by tillage. If the measurement is made over a small area, the slowly permeable layers may cause the infiltrating water to move horizontally as well as vertically, resulting in an abnormally high value for the infiltration rate. Evans *et al.* (1951) have discussed this situation in detail, and Erie (1962) has discussed the evaluation of infiltration measurements.

The studies of Van Bavel *et al.* (1968) and Rose and Stern (1965) have shown how soil water flow theory can be used to describe the dynamic nature of soil water in cropped soils. Although advances have been made in applying soil-water flow theory to field situations, the accuracy of the results when applied to large land areas remains to be evaluated. Furthermore, the present theories of infiltration and water movement within the profile do not account for the observed fact that infiltration rates and sometimes water flow rates in the profile, decrease as the growing season progresses. This may be the result of tillage operations, the interaction of salt with the soil particles to cause dispersion of aggregates, or other factors. More research is needed in this area to further develop the best soil and water management practices for optimum crop growth and water savings.

7.2.2. Salt and water movement

Salts move within the soil profile by being carried along with moving liquid water and by diffusion. From fundamental studies of salt and water movement during the past ten years a clearer concept of the leaching of salts from the soil profile has evolved, leading to recommendations of new leaching practices.

The size of pores and channels through which water flows in soil varies from millimicrons to millimetres. The rate of water flow through these channels is approximately proportional to the square of the radius of the channel. Thus, large channels conduct water much faster than the smaller ones, and most of the water moves through the large channels. Salt accumulations in the soil are distributed throughout the range of channel sizes. If water is ponded on the soil surface, the soil becomes saturated and most of the flow takes place through the large channels. Salts in these channels are flushed out, but salts remain in the smaller pores. After the ponded water infiltrates and the soil becomes unsaturated, the large channels drain, and the flow of water and salt continues through the smaller pores. If the soil is unsaturated, less water is required to remove an equal quantity of salt than if the soil is saturated.

This phenomenon is exemplified by Fig. 2 taken from a study by Nielsen *et al.* (1964).

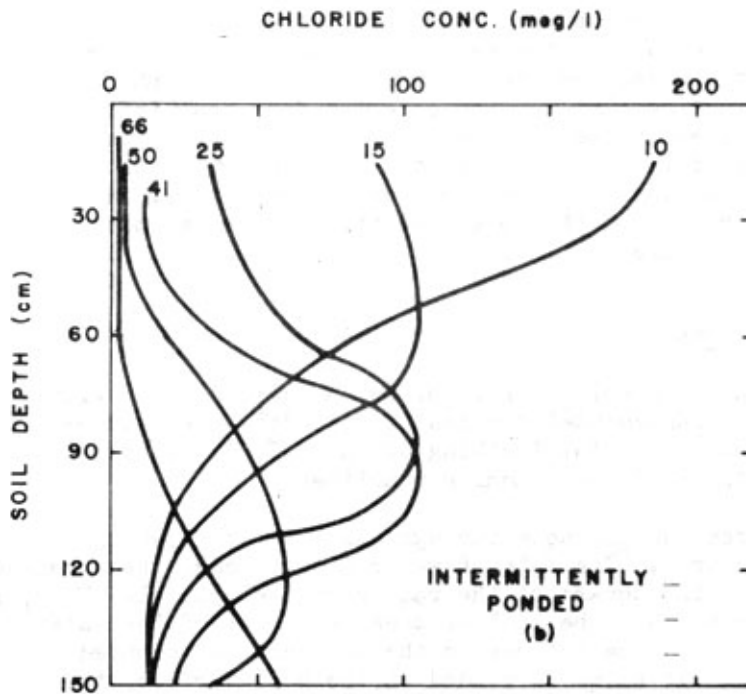
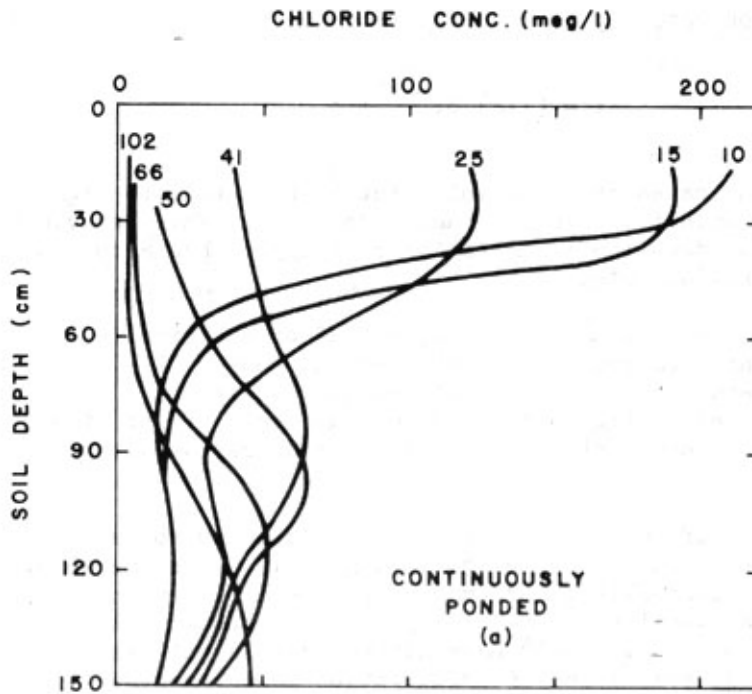


Figure 2. Distribution of chloride concentrations in the soil solution of Panoche clay loam when the soil surface was (a) continuously ponded and (b) intermittently ponded with irrigation water. Numbers on each curve represent the centimetres of water that had infiltrated at the time of measurement (Nielsen *et al.* 1964)

The chloride concentration as a function of soil depth is shown for a continuously ponded (Fig. 2 (a)) and an intermittently ponded treatment (Fig. 2 (b)). Comparison of curves in the two figures for the same amount of water infiltrated shows that the intermittent ponding treatment moved more salt to lower depths in the profile. The concentration of salt at all soil depths down to 137 cm was less with 66 cm of intermittently ponded irrigation water than with 102 cm of continuously ponded water. The continuously ponded treatment caused the salt to be spread through a greater depth of soil before being leached out of the profile.

Oster *et al.* (in press) compared the salt-removing efficiencies of continuous ponding, intermittent ponding and sprinkler irrigation. They found that for all treatments salt reduction was most rapid immediately after the first application of water. Their study confirmed results from earlier studies and demonstrated that leaching by intermittent ponding or sprinkling used less water than continuous ponding and achieved the same degree of leaching in the same period of time on their soil.

The fact that salt is readily leached from soil even when the soil-water content is relatively low raises the question of how dry the soil must be before salt does not move. In a bare soil, salt accumulates near the surface as a result of water moving to the surface and evaporating. Nakayama *et al.* (in press) have shown that salt accumulates largely in the 0 to 0.5 cm layer of bare soil. By observing the water content at which salt accumulation reached the maximum, they determined that salt moved with liquid water at water contents as low as 0.04 volume fraction for a loam soil. For this soil the saturated water content was about 0.42 and at 15 bars it was 0.15. The 0.04 water content corresponds to a relative humidity of about 0.4. These data are supported by soil-water diffusivity measurements shown in Fig. 3. In the figure the solid circles and solid triangles represent measurements of liquid flow. Data represented by the solid circles were obtained by measuring soil-water diffusivities at several pressures (Jackson, 1965). Since water vapour flow is proportional to the reciprocal of the pressure, a plot of soil water diffusivity versus the reciprocal of pressure yielded a straight line from which

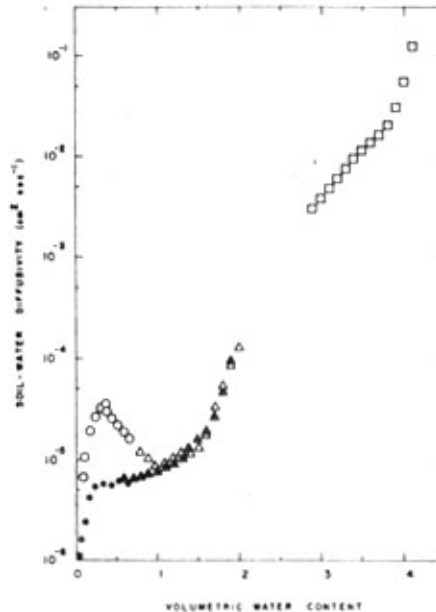


Figure 3. Soil-water diffusivity as a function of volumetric water content. Solid symbols represent liquid flow. Open symbols represent the sum of liquid and vapour flow.

the diffusivity for liquid flow was obtained by extrapolation. The solid triangles represent data obtained by placing soil columns in a chamber held at 15 bars pressure, and the open triangles represent data taken at atmospheric pressure. The solid triangles, therefore, represent liquid flow, whereas the open triangles represent the combination of liquid and vapour flow. The open circles are taken from Jackson (1964) and represent both liquid and vapour flow, with the vapour predominating. The open squares represent data for predominately liquid flow at water contents near saturation (Jackson, 1963). These data indicate that liquid flow occurred at water contents as low as 0.04 volume fraction, in support of the conclusions of Nakayama *et al.* (in press).

Evidence that salt will move with liquid water at low water contents lends support to the concept of leaching with intermittent ponding or sprinkling. This concept of leaching is inherent in the "leaching efficiency" proposed by Boumans and Van der Molen (1964) as discussed by Bouwer (1969), described in the following section.

7.2.3. Leaching requirement and efficiency

Soluble salts are leached by applying a sufficient amount of water so that some water passes completely through the root zone. Leaching practices are determined by the quality and amount of irrigation water, the kind and quantity of salt in the soil, the ability of the soil to conduct water, and the drainage status. This requires that a leaching practice be tailored for a particular farm. A leaching practice may be to irrigate before planting with enough water to flush most of the salts through the root zone. Subsequent irrigations may be less and may allow some salt build-up. Other practices call for applying sufficient water at each irrigation to leach the root zone. A "rule of thumb" that has been used for many years is to apply a centimetre of water for each centimetre of soil to be leached. That "rule" can only apply when the irrigation water supply is ample, when adequate drainage is available and when the return flow of drainage water to the river or groundwater basin does not adversely affect the salinity of those waters.

The leaching requirement may be defined as the fraction of irrigation water that must pass through the root zone to reduce the salt concentration to a specified level. A method of calculating the leaching requirement is essential if adequate leaching with a high irrigation efficiency is to be achieved. The United States Salinity Laboratory Staff (1954) proposed a method for calculating the leaching requirement for a particular soil. Their method is well known and is at present a standard reference. Bernstein (1967) has elaborated upon their method. Bouwer (1969) proposed an alternative method of arriving at the leaching requirement.

The salt balance between irrigation water and drainage water can be expressed as

$$d_i c_i = d_d c_d \quad (8)$$

where d_i is the depth of irrigation water applied, d_d the depth of water draining from the root zone, c_i the salt concentration of the irrigation water and c_d the salt concentration of the drainage water. The salt concentration terms may be expressed in terms of electrical conductivity, which is a convenient method of measuring salt concentration.

The leaching requirement (LR) is (Bernstein, 1967)

$$LR = c_i / c_d = d_d / d_i \quad (9)$$

In practice, c_d is estimated from the salt tolerance of the crop to be grown. Salt tolerance of crops is based on measurement made on the saturation extract (c_{se}). The procedure involves preparing a soil paste by adding distilled water until a characteristic end point is reached and then extraction of some water by use of a suction filter. Salt tolerance tests usually are conducted on artificially salinized plots in which the salts are distributed more uniformly than in a field soil. Thus, the concentration of salts in the soil solution (c_s) in the plant environment is not necessarily the same as in the saturation extract (c_{se}). Different crops, for the same level of yield reduction, may have c_{se} values that differ by a factor of ten.

Defining d_e as the amount of irrigation water required for evapotranspiration, the amount required for irrigation is $d_i = d_e + d_d$. Substituting into equation (9) and rearranging, yields

$$d_i = d_e / (1 - LR) \quad (10)$$

which is the depth of irrigation water necessary to meet the leaching requirement.

Equation (10) applies to a soil whose infiltration rate is uniform over the entire field when water is applied uniformly over the entire field. Such uniformity is almost never found in practice and irrigators must generally apply more water than is necessary to compensate for the non-uniformities. Therefore, equation (1) must be modified

$$d_i = \beta d_e / (1 - LR) \quad (11)$$

where β is the nonuniformity factor. Its value usually ranges from 1.1 to 1.2. It is a factor that is best obtained by practical experience.

Boumans and Van der Molen (1964), as discussed by Bouwer (1969), stated that the salt concentration of the soil solution (c_s) is not only not the same as the saturation extract (c_{se}), but also not necessarily the same as the concentration of drainage water (c_d). Using concepts similar to those discussed in the section 7.2.2: Salt and water movement, they argued that irrigation water flowing through the large channels would contain little salt and the water passing through the finer pores would contain salt in close proportion to the soil solution concentration that plants are exposed to. They considered the water draining from the root zone to be a mixture of the applied irrigation water that passed unchanged through the root zone and soil solution directly displaced by irrigation water. The fraction of drainage water consisting of displaced soil solution has been called the leaching efficiency (Bouwer, 1969 and references therein). The leaching efficiency (LE) is

$$LE = (c_d - c_i) / (c_s - c_i) \quad (12)$$

where c_s is the salt concentration of soil-water in the root zone. The theoretical maximum of LE is one, which can be achieved only if the soil solution is completely displaced by piston flow of the irrigation water. This has nearly been achieved in column studies with structureless soils, but almost never occurs in the field. In field soils, cracks, rootholes, wormholes and other large diameter channels, plus the inherent non-uniform water application cause LE to be appreciably less than one. Field experiments (Boumans and Van der Molen, 1964) have shown that LE is about 0.2 for fine-textured soils (where cracks, rootholes, etc. may abound) to 0.6 for coarse-textured soils (where pore sizes are more uniform). For sandy soils LE may be about 0.8.

Bouwer (1969) defined the efficiency of water utilization (E_u) to be

$$E_u = d_e/d_i = 1 - d_d/d_i \quad (13)$$

(the term E_u should not be confused with the water use efficiency, which expresses dry matter production in relation to water use.) Using (12) in (13) yields

$$E_u = LE(c_s - c_i) / [c_i + LE(c_s - c_i)] \quad (14)$$

Use of equation (14) requires the assessment of irrigation water quality (reflected in c_i), a knowledge of the salt tolerance of the crop to be grown (reflected in c_s), and an estimation of the leaching efficiency LE. Advantages of (14) are that the value of c_s is more nearly representative of the soil solution concentration for which the salt tolerance of crops has been evaluated and that LE can be estimated from the soil texture of the field to be irrigated. Bouwer (1969) tested this concept by using data from the San Joaquin and Coachella Valleys in California and for the Murray River irrigation areas in Australia. He found excellent agreement between his calculations and the published results.

The concept of leaching requirement can also be put in terms of water utilization efficiency. Using equations (9) and (11) in (13) yields

$$E_u = (1 - c_i/c_d) B \quad (15)$$

The terms LE in (14) and B in (15) are both empirically evaluated. Additional research may lead to reliable means of predicting them from soil physical and chemical principles. Field research is needed to obtain values of LE and B using optimum water management practices. Both approaches need evaluating under intermittent ponding or sprinkling leaching practices.

7.2.4 Drainage

Inherent in the previous discussions concerning water and salt movement in the soil profile was the assumption of adequate drainage. In many calcareous soils natural drainage is sufficient, but in others artificial drains must be installed to accommodate part, if not all of the drainage water. The drainage system should be designed to prevent high water tables when leaching is practiced during the growing season and should keep the water table sufficiently low between growing seasons to minimize evaporation and the consequent salt accumulation in the root zone.

Bouwer (1972a) has drawn a distinction between the terms drainage requirement and design requirement. Drainage requirement is the total drainage required for a given field or region and design requirement is the difference between the total drainage needed and the existing natural drainage. Drainage requirements have been the subject of numerous technical publications. The American Society of Agronomy is publishing their second monograph on drainage entitled "Drainage for Agriculture," which summarizes much of the latest drainage research.

Most drainage theories are concerned with a saturated system. For irrigated calcareous soils, the drainage below the root zone may be predominately in the unsaturated state. If artificial drainage is required, the design of such a system requires that the response of the water table to the influx of root zone drainage be calculated for different drain spacings, so that the optimum combination of spacing (as it affects

drainage costs) and water table response (as it affects crop yield) can be selected. Calculation of water table response to root zone drainage requires that the drainage rate be known as a function of time. Expressions such as equation (5) that predict drainage below the root zone (Fig. 1) are adequate. Other equations for this purpose are discussed by Bouwer (1969).

In calculating the drainage requirement it is necessary to account for water used for leaching. Bouwer (1972b) has incorporated the concept of leaching efficiency in drainage design. Additional research concerning the application of soil water flow theory to prediction of drainage rates in unsaturated soil, including the required leaching, may improve drainage efficiency.

7.3. Management Aspects and Practices

For many years soil and water management practices were concerned only with the root zone. The quality (and often the quantity) of water leaving the root zone was of no consequence. As a result many lower areas, once productive, developed high water tables and high salt concentrations, rendering them useless for agricultural purposes. The return flow of drainage water to rivers and streams was unabated and tended to increase the salt content of irrigation waters for downstream users. Not only downstream farmers, but other interests, were affected as the competition for available water between municipal and agricultural interests increased.

One solution is the creation of salt sinks. On the farm, soil and water management practices may be implemented to store salt leached from the root zone in the vadose zone between the root zone and the groundwater table. Salts may be stored in groundwater basins in areas where these waters are not utilized. Evaporation lakes may be created to concentrate the salts. In some cases it may be necessary to construct desalinization plants to purify the water before returning it to the rivers or groundwater. Social and political pressures are causing researchers to seek new management practices on the farm, district and river basin levels.

7.3.1 Tillage practices

As noted earlier, infiltration rates can be altered by tillage. Where water movement through the soil is restricted, thus limiting the leaching of salts, deep tillage is necessary. Some soils are chiselled, slip ploughed or deep mouldboard ploughed to depths of 1.2 to 1.5 metres. Such tillage must be done when the soil is relatively dry in order to break up the impervious soil layers. Large, powerful machinery is necessary for these operations.

Sometimes the surface layers of soil are pulverized and compacted by excessive tillage. This results in a low intake rate and prolongs irrigation times. The practice of minimum tillage (Harris *et al.* 1965) is recommended for these conditions. Minimum tillage simply means that only those operations necessary to open up the soil for a seedbed and plant the seeds are performed. Whenever possible, chemical means should be utilized for weed control instead of cultivation.

Harris *et al.* (1965) measured infiltration rates in a calcareous soil to evaluate the effects of compaction by tractor wheels on a ploughed soil. They found that infiltration rates in the compacted areas were 43% of those in the noncompact area. Low infiltration rates persisted for 2 years during which the field was cropped to alfalfa.

Minimum tillage is essential on some soils to insure adequate leaching of salts. Erie (unpublished data) has conducted studies on a silty clay soil in eastern Arizona. The irrigation water contained 2 500 to 4 500 ppm of salts, with a sodium percentage of

78%. After ploughing, with no other tillage, the soil was irrigated with 20, 30, 45 and 60 cm of water. In some instances the 60 cm treatment could not be completed because the intake rate became less than the evaporation rate. The 30 and 45 cm treatments reduced salts enough for germination to take place and a reasonable final yield was obtained. Yields of cotton, barley and sorghum were less on the 20 cm treatment. Subsequent irrigations were just sufficient to provide water for plants. Because the infiltration rates decreased after each irrigation, intermittent ponding to achieve leaching would probably not be feasible with this soil.

Although irrigated calcareous soils are susceptible to compaction by heavy equipment, some tillage is necessary. Furrow-irrigated crops are cultivated using various planting and bed shaping techniques to control the water in such a way as to lower salt content around the germinating seed. For example, cotton is planted in ridges for this purpose. First the field is furrowed and a preplant irrigation is given to leach salts. After the preplant irrigation, the top 5 cm of the ridge (containing a higher concentration of salts than the surrounding soil) is pushed to the side, the seeds are planted immediately in the same operation in the freshly exposed soil and a ridge is formed over the seed to maintain moisture. After about four days, about 5 cm of the ridge is removed to allow the sprouting plants to emerge. These operations serve to control both moisture and salts.

In some cases where the irrigation water and the soil are very salty and the land is level, seed is planted in the level soil so that the maximum amount of salt will be leached from the seedbed. If it is necessary to use furrows the seeds may be planted in the bottom of the furrow to achieve maximum leaching from the seedbed. In such soils crusting may be a hazard; therefore, the type of seed must be considered.

Some crops such as cantalopes may require warm seedbeds. To utilize the sun's energy, planting beds are constructed sloping and facing toward the sun. To cope with salts, the seeds are planted 5 to 8 cm above the expected height of water in the furrow. This decreases crusting and allows salts to be leached up the bed slope away from the seeds.

Tillage for optimum irrigation and control of salts appears to be a fertile area for additional research. Often tillage for one purpose may be detrimental for another. Research should be geared to optimize as many factors as possible.

7.3.2 Irrigation practices

The main purpose of irrigation is to provide water to a growing crop. Yet it has been estimated that 42% of the water delivered to the farm is not used by plants for evapotranspiration (Erie, 1968). This appears wasteful until one considers that irrigation water is often applied for such purposes as to aid germination, to protect from frost, to control corn borers and caterpillars, to maintain crispness in lettuce and other vegetables during harvest, to leach salts and to dissolve fertilizers. Thus, many factors other than evapotranspiration must be taken into account by management practices. These practices must deal with how, when and how much water to apply, and the reason for the irrigation (Erie, 1968).

Many factors must be considered when selecting an irrigation method: available water, quality of water, topography, type of soil, crops to be grown and economics. Four basic irrigation methods are: basin, furrow, sprinkler and trickle or drip. With the advent of new plastic pipe and tubing designed specifically for irrigation, trickle or drip irrigation is receiving increasing attention from researchers throughout the world. This method allows excellent control of placement and amount of water. Furrow,

sprinkler and trickle methods can be used on sloping lands. Furrows may be constructed on contours to reduce erosion and increase infiltration. Sprinklers, like trickle systems, may be used on almost any topography.

With sloping furrow or basin systems, field supply ditches are frequently constructed of concrete with gates installed to facilitate rapid changes of water sets. This system is readily amenable to the reuse of water on lower elevation fields. The runoff water is collected in ditches for diversion to other fields or in reservoirs at the lower ends of fields from which the water is pumped back to the higher elevations for reuse.

Basin irrigation requires the land to be level or only gently sloping. A definite trend in the southwestern United States is to construct basins "dead level." Dead-level basins usually range from 2 to 16 hectares in size and require large streams of water, usually 10 to 30 cfs (0.3 to 0.8 m³/sec), in order to cover the entire basin as rapidly as possible. Dead-level basins are perhaps the most efficient system available from the point of view of water application efficiency and salt control. There is virtually no runoff and the amount applied can be controlled accurately. This degree of control allows salts to be leached from the root zone with a minimum amount of applied water.

Runoff sediment from basins is nil; however, because of the large supply streams, erosion near the basin inlet structures can be serious. In some cases entire supply ditches have eroded away. Research has shown (Erie, unpublished data) that an energy absorber and spreading apron can be constructed of concrete in place to reduce erosion.

7.3.3 Irrigation scheduling

The timing of irrigation and the amount of water to be applied are important factors in a management programme. Significant advances have been made in the science of irrigation timing; yet, in many respects it remains an art practised successfully only through years of experience (Kyaw and Wilson, 1972). Also, the insistence of an individual farmer to make his own mistakes is a result of the scientific community not being able to "sell" their expertise (Walker and Walker, 1972).

Frequently, more water is wasted by not knowing when to irrigate than by poor application practices. Much research has been conducted to determine the proper times to irrigate specific crops. Consumptive use estimates have been developed for many crops in the irrigated areas of the United States (Erie et al. 1965). With consumptive use data for a particular crop and a knowledge of when to give the first irrigation (pre-planting, germination, etc.) calendar dates for when to irrigate can be forecast. The forecast is appreciably better in areas where rainfall contributes little to the crop water supply. Consumptive use data for one area will not be valid for another area having widely different climatic conditions without proper conversion factors. Several methods for assessing the conversion factors have been proposed. These methods have met with various degrees of success.

An irrigation scheduling system using a computer has become relatively successful (Jensen, 1969, 1972). This system combines meteorological, soil and crop data to predict irrigation dates and amounts. The system consists of a computer programme that analyses specific fields for individual farms. Past and predicted meteorological parameters, date and amount of last irrigation, an empirical crop factor, soil data and information from the farmer concerning management operations are entered into the programme. The computer then predicts the date and amount of the next irrigation.

This programme was revised and adapted for use by the Salt River Project in Phoenix, Arizona (Kyaw and Wilson, 1972). In addition to the computer programme the Project utilizes repetitive field checks by trained specialists. These specialists work directly with the farmer and check the soil moisture and crop status on individual fields. The

combination of field checks and computerized information is intended to maximize the efficient use of water by confining water application to just that amount needed to satisfy consumptive use and leaching requirements. Another benefit of this programme is the potential for improvement of operational services. The programme can forecast the demands for actual water delivery as much as 2 weeks in advance of need. At present the Salt River Project is cooperating with the National Aeronautics and Space Administration in preliminary studies using remote sensing from aircraft as a possible tool for use in irrigation scheduling.

7.3.4 River basin salinity control

The continuous accumulation of salts within river systems has stimulated projects to reduce inflow of salt to the river (Holburt, 1972). The point source control of salts is the diverting of waters from localized salt sources such as mineral springs and outcropping of soluble formations adjacent to or underlying surface water sources, and drainage water from irrigation projects. These sources usually can be controlled, if funds are available for construction of needed structures. To carry water over formations containing soluble salts, reservoirs and impervious channels need to be constructed. Outflows from mineral springs require desalting plants to remove the salt.

Diffuse-source salt control projects have been designed to control contributions from a larger area than point source project. The basic concept is selectively to remove the saline low flows from a stream and to bypass the less saline high flows. The low flows would be desalted. The third project is irrigation-source control. Soil and water management (including irrigation scheduling) is the key to this project. Construction and improvements of existing water conveyance systems are important also.

Computer simulation models of river basins have been devised to aid in salinity control (Hyatt, 1972; Wilson, 1972). The models describe only the basic processes in the system and have value in predicting water quality changes that might result from future development at a particular location within the river system. A computer model has also been developed to describe water and salt movement within the root zone of a crop (King et al. 1972). Models such as this should aid in the timing of soil and water management practices.

7.4. Concluding Remarks

Agricultural societies that rely on irrigation are faced with a dilemma. If irrigated agriculture is to continue, the salt concentration in the root zone must be kept low. If this is done, the quality of return flow water to rivers and groundwaters is degraded by the increased salt content. On the other hand, this degradation can no longer continue. Good quality return flow must be maintained in order to serve other essential elements of the society.

To maintain good quality return flow water by having neither leaching to groundwater nor runoff presents a formidable challenge to agricultural research. Future management practices should use water to the maximum of efficiency and move salts below the root zone to be stored between the bottom of the root zone and the top of the capillary fringe above the water table. To accomplish this goal, additional research is required in areas such as water movement into and through soil, water use efficiency, consumptive use of water by crops, salt tolerance of crops, removal of salts by precipitation in insoluble forms, leaching requirement or efficiency, and irrigation structures.

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DISCUSSION

The question of the use of bitumen as a treatment to reduce soil crusting was raised. Bitumen may be sprayed on a small area directly over the seed after planting or as a band over the seed row. In addition to reducing crusting the black material increases the absorption of solar radiation and therefore soil temperature. It also reduces evaporation of water. These factors improve the seed environment. Experiments have shown the feasibility of this treatment but it has not been generally adopted as a management practice.

A question was raised concerning what chemical reactions occur when H_3PO_4 is sprayed on the soil surface to reduce crusting. The question was not resolved.

The method of "dead level" irrigation was discussed. This type of irrigation is usually carried out on soils that are relatively flat and do not require excessive levelling. The length of run in such a system depends upon the type of soil, the quantity of available water and the means of applying this water rapidly.

Pan evaporation as an indication of when to irrigate is used in some countries in the Near East. This method is used to some extent in the U.S.A. but is not the predominant one. Consumptive use studies and a computer based system are being used to a larger extent.

The possibility of using remote sensing techniques to determine soil moisture status was discussed. Infra-red and microwave radiometers are being tested in the United States to ascertain their usefulness. The method is in the early stages of testing and it is too early to say how successful it will be.

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8.1. Introduction

The Ghab Valley is situated in the north-west of Syria and in the lower part of the Orontes Basin. The Valley is about 50 km long and with an average width of about 10 km. Before reclamation the greater part of the Valley was occupied by perennial and seasonal marshes. The project for the reclamation and agricultural development of the Valley was, therefore, first and foremost a drainage project. After the construction of the main irrigation and drainage network, the net irrigable area was about 43 000 ha, out of which about 26 000 ha was under marshes. The average rainfall which falls during the winter season (October-April) increases from 600 mm in the south-east to about 1 000 mm in the north-west giving an average of about 800 mm for the whole Valley. In view of this, the Valley is rather wet during the winter months which requires drainage to get rid of the excess rainfall. On the other hand, during the dry hot season of the summer months (May-September) irrigation is necessary for the production of perennial and summer crops.

The Ghab has been a lake at different times and the sediments in this lake form a continuous cover on the bottom of the depression. The lower deposits are of about 100 to 200 m thickness and consist of sandy marls and chalky marls which are relatively impervious. The upper sediments are of a more recent origin and belong to the end of the Pliocene and Quaternary and partly of recent origin. They are composed of relatively impermeable grey plastic marl of lacustrine origin. Their thickness is more than 40 m. The most recent and present day deposits consist of alluvial deposits, hillside wash, recent and present day river levees, recent and present day marsh and lake deposits and lakeshore deposits. These deposits form the parent material of the different agricultural soils in the area. It becomes clear that nearly all the soils of the irrigable land in the Ghab Valley are undifferentiated alluvial and lacustrine soils.

As mentioned above, more than 50% of the Ghab Valley was either perennial or seasonal marshes. The main characteristic of these soils is their high content of organic matter, whereas under the climatic conditions of the region, the equilibrium of the organic matter content of a normal well drained soil is about 2%. Before draining the area, the Ghab perennial marshy soils had an organic matter content ranging from 8 to 45%. Ever since the marshes disappeared, after the construction of the main drainage network the oxidation of the organic matter took place rather fast. At present, the average organic matter content is from 5 to 10%.

8.2. The Organic Calcareous and Marly Soils of the Ghab Valley

Strictly speaking, all the soils of the Ghab Valley could be called calcareous soils because the calcium carbonate content is not less than 20% for any soil type.

However, for our present purpose, we will discuss only two soil types which have a calcium carbonate content of more than 60% and which belong to the soil series of the perennial marshes. In the perennial marshes, the peat is formed by the growth of higher plants such as carex and reed in shallow and moderately deep water respectively. In deep water, only primitive plants such as characae diatoms and other monocell plants can thrive. These plants have the characteristics of accumulation of CaCO_3 in their tissues and gave rise to the lacustrine marls.

Broadly speaking, there are two types of soils; one type which is the most widely spread is highly calcareous soils overlaid by powdery humic substance. These soils are light to medium-textured loamy soils characterized to very high calcium carbonate content (60 - 80% CaCO_3). The other type is marly soil with calcium carbonate content of more than 70% and organic matter of about 5%. They are powdery and dusty when dry and without any cohesion. If worked wet, they dry out to hard blocks. From the physical point of view, these soils are very poor with a low clay content and the water holding capacity is low (about 14%). From the chemical point of view, they should be considered as poor, except for the fact that they have a relatively high organic content of 5 to 10% which will eventually be reduced to about 2% as mentioned before, if certain precautions are not taken. The following is a typical analysis of these soils:

| (1) | <u>Physical Properties</u> | <u>Marly Soil</u> | <u>Organic Calcareous Soil</u> |
|-----|----------------------------|-------------------|--------------------------------|
| | Sand | 60% | 40% |
| | Silt | 25% | 50% |
| | Clay | 15% | 10% |
| | Wilting Point | 15% | 20% |
| | Water Holding Capacity | 30% | 34% |
| (2) | <u>Chemical Properties</u> | | |
| | Organic Matter | 51% | 8% |
| | Total Nitrogen | 0.40% | 0.45% |
| | P_2O_5 | 50 ppm | 75 ppm |
| | CaCO_3 | 75% | 65% |

8.3. General Remarks on the Management of the Ghab Calcareous Soils

As mentioned before, the top humic layer was classified before drainage as peat (about 40% organic matter), it has dropped to about 8% after about 10 years of drainage. It can be concluded that under the prevailing climatic conditions (summer mean average temperature of 26°C) and cultural practices, the organic matter content may reach in future an equilibrium value of 2% as is the case in normal and well drained soils in the region.

The answer to the question how long it will take to reach this equilibrium value will depend on the management of these soils. The soil fertility problem, at present, does not look so serious, thanks to the nutrient release from the organic matter reservoir. The decomposition and depletion of this reservoir may create a serious problem in the future especially where this humic soil is overlying a highly calcareous sub-soil. To delay the decomposition of the powdery humic substance of the top soil and also the bands of organic matter which are found frequently imbedded in the soil profile at different depths up to 150 cm, certain precautions should be taken. Beside keeping the soil moist as long as possible by the proper irrigation and drainage practices, which will be the subject of this paper, other items such as the minimum disturbance of the soil surface through ploughing and cultivation and the protection of the top soil from wind erosion by keeping the crop stubble together with the use of windbreaks. Another alternative is to plough in the top humic soil with the marl below. It is argued that due to the fact

that the clay minerals in the marl are mainly of montmorillonite type, which has the property of preserving the organic matter, and this ploughing in of the top humic layer with the marl below, will help to conserve the organic matter for a longer period of time.

8.4. Irrigation of Calcareous Soils of the Ghab

8.4.1 Basin Irrigation

Basin irrigation is the predominant method of irrigation in the Ghab and will probably continue for some time to come. When practised correctly, it could be an efficient method of water application, provided that the required labour is available to guide the water carefully from basin to basin. Because of high infiltration rate and no soil levelling, small basins of about 5 m x 7 m are used at present. The depth of irrigation varies from 150 to 200 mm and not more than 50% of irrigation application efficiency is obtained. Larger sizes of basins could be used and with higher application efficiencies. Simple land floating will be sufficient in most cases. Only in a few places, movement of the earth by tractors and scrapers followed by large land planes for finishing the grade will be required. Every two or three years, land which is cropped yearly should be land planed in order to obliterate the microrelief which will develop with standard cultural practices and to land subsidence through sub-soil shrinkage due to drainage and oxidation of the organic content of soil. The main objections to basin irrigation are its requirement of high labour, obstacle to mechanization and the loss of a good percentage of land for ditches and levees.

8.4.2 Sprinkler and Drip Irrigation

The soil infiltration rate of these soils is very high as it ranges between 8 cm to 20 cm/hr. Under such conditions, sprinkler or drip irrigation seem to be the most suitable irrigation methods. However, due to the high velocity of the wind which could be more than 5 m/sec and to the erratic nature of the winds the use of sprinklers is precluded over much of the area. The high cost of capital investment (500 - 1000 Syrian Pounds/ha) and the operation and maintenance of sprinklers introduce a limiting factor to their extensive use in the Ghab. Sprinklers may be satisfactory in wind-sheltered areas for the production of high value speciality crops.

Drip irrigation could be used to advantage in the high infiltration soils with high wind velocities. This method of water application is a relatively new one and its cost is expected to be quite high ranging from 1 000 to 1 500 Syrian Pounds/ha. Nevertheless, it may be well worth-while to carry out field experiments on this method of irrigation under the Ghab conditions which may prove to be suited for row crops of high cash value.

8.4.3 Sub-Irrigation

These soils form the bottom areas of the Ghab Valley. Where large blocks of single crops are grown on them, a system of sub-irrigation could be practised more intensively than at present. By manipulating the water in the drain ditches, a raising and lowering of the water table could be practised in order to saturate the soil profile to the depth of rooting of the crop and then by releasing the water, to allow the profile to drain to field capacity. This method of irrigation requires care in grading the land and in manipulating the water table.

In every method of irrigation, a degree of land grading is necessary, the greatest accuracy is required for sub-irrigation and for surface methods in which the ground surface is used to convey water.

8.5. Drainage of the Calcareous Soils

8.5.1 Optimum depth of underground water table

A lysimeter experiment was carried out in the Ghab Project in 1967-1970. The main objective of this experiment was to find out the optimum depth of underground water table in relation to yield of crops and the economy of irrigation water.

8.5.1.1 Effect of underground water depth on crop yields

The effect of underground water depth on crop yields was studied in the Ghab with two different soil types (light organic calcareous soil and heavy clay soil) using different static depths of underground water ranging from 30 cm to 120 cm using lysimeters. The crops included in this study for the light organic calcareous soil were cotton and alfalfa. The summary of these results is indicated in Table 1.

Table 1. Effect of undergroundwater depth on crop yield in lysimeters in organic calcareous soil - figures are % of maximum yield

| Crop | Depth of Water Table in cm Below Ground Surface | | | | | | | | | |
|------------------|---|----|----|-----|-----|----|----|-----|-----|-----|
| | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 |
| Cotton | - | 55 | - | 100 | - | 90 | - | 85 | - | 65 |
| Alfalfa 1st Year | 76 | - | 80 | - | 100 | - | 94 | - | 83 | - |
| 2nd Year | 53 | - | 70 | - | 81 | - | 80 | - | 100 | - |

From the above table, it can be seen that maximum yield of cotton in light organic calcareous soils was obtained at about 60 to 80 cm depth of water table. In the case of alfalfa, maximum yield was obtained at water table depth of 70 cm in the first year, but in the second year it increased to 110 cm.

8.5.1.2 The effect of water table depth on its contribution to the root zone

The kind of crop grown and its stage of development and type of soil all have an influence on the amount of water that can be extracted from the water table. The summary of these results is shown in Table 2 below.

Table 2. Water table contribution as % of total consumptive use of crops in lysimeters in organic calcareous soils

| Crop | Underground Water Depth in cm | | | | | | | | | |
|------------------|-------------------------------|----|----|----|----|----|----|-----|-----|-----|
| | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 |
| Cotton | - | 70 | - | 52 | - | 35 | - | 28 | - | 13 |
| Alfalfa 1st Year | 78 | - | 65 | - | 53 | - | 51 | - | 41 | - |
| 2nd Year | 80 | - | 70 | - | 60 | - | 55 | - | 47 | - |

From Table 2, it can be noted that cotton was extracting about 50% of its requirement from the water table at a depth of 60 cm, but this contribution declined rapidly with increasing water table depth, as it was only 13% of the total at a water table depth of 120 cm. Alfalfa was more active than cotton in this respect and it improved its performance during its second year as compared with the first year. Alfalfa was still extracting about 50% of its total requirement from the water table at a depth of 90 cm during the first season and nearly the same percentage at a water table depth of 110 cm during the second season. This indicates that the contribution of water table to the crops is effected to a great extent by the activity of the root system, of the plant itself.

From the above discussion it could be concluded that the optimum depth of water table in light organic calcareous soils in relation to yield of crops and the economy of irrigation water is about 70 cm for cotton and 100 cm for alfalfa, giving an average water depth of 80 to 90 cm for the project as a whole.

8.5.2 Optimum depth of field drains

The optimum depth of field drains is governed by several factors, the most important of which are the cost of construction, the hydrological properties of the soil profile and the optimum depth of underground water to be maintained. The latter is governed by the yield of the crops, the salinization hazard and the utilization of water from the water table by the crops and hence, the economy of irrigation water use.

The cost of construction of field drains with the available machinery on the market does not increase noticeably from 1.0 to 1.8 meters. Beyond 1.8 meters much heavier machinery is needed and cost increases rapidly.

The study of the hydrological properties of the soil profile indicated that the top 2 to 2.5 metres of the soil profile of these calcareous soils is of high permeability of about 10 to 12 m/day.

Below this depth there exists a nearly impermeable layer of grey marl which, as has been indicated before, extends for a thickness of several hundred metres. Consequently, it is important that field drains should never be placed in this impermeable layer of grey marl.

The studies on the optimum depth of underground water which has been discussed before, indicate that the optimum depth of water table seems to be around 80 to 90 cm in the light organic calcareous soils and marly soils.

As mentioned before, these calcareous soils have a high infiltration rate which means that by the use of the conventional surface irrigation methods, a large portion of the irrigation water will be lost during irrigation to the water table. At present, with the use of small irrigation basins, but without land smoothing, the depth of the irrigations ranges between 150 to 200 mm and with irrigation application losses of more than 50%. Even with land smoothing and the use of other methods of surface irrigation (furrows or borders), this situation could not be improved very much. The use of sprinkler or drip irrigation which is most suitable for these types of soils is not likely to be carried out on a large scale in the Ghab project for many years to come. This is mainly because of the high capital, operational and maintenance costs of such systems. Consequently, it is expected that high losses of irrigation water to the water table will continue and every effort should be made to utilize some of this lost water. This could partly be achieved by keeping the water table relatively high so that crop roots could extract some of their requirements from the water table.

Due to the heavy winter rainfall in the Ghab, which amounts to about 600 mm in the south and 1 000 mm in the north and with an average of 800 mm, sufficient leaching is provided so the problem of soil salinization by capillary action from shallow water table should not arise once the necessary field drainage network is installed.

Taking all the above factors into consideration, and remembering that most of the crops in the Ghab will consist of cotton, alfalfa, sugar beet and vegetables, it seems reasonable to conclude that the optimum average depth of the field drains in the Ghab should be in the region of 130 cm in the organic calcareous soils and marly soils.

8.5.3 Spacing of field drains

To estimate the spacing of field drains, it is necessary to determine first the following:

- 1) the drain depth
- 2) the drainage criteria
- 3) the hydrological properties of the soil profile; and
- 4) the formula to be used in calculating drain spacing.

8.5.3.1 The optimum depth of field drains

As has been discussed before, and after taking into consideration all factors concerned, it was concluded that the optimum depth of field drain should be about 130 cm below the ground surface.

8.5.3.2 The drainage criteria

The drainage studies in the Ghab for several years have indicated that the drainage criteria should be based on the control of water table during the winter rainy season. The drainage criteria which have been adopted and which are based on the results of field drainage experiment and on the analysis of the quantities and distribution of winter rains for the organic calcareous soils and marly soils are as follows:

- i) Drainage runoff of 8 mm/day with water table 50 cm below the ground surface in the north-west of the Ghab
- ii) Drainage runoff of 6 mm/day with underground water table 50 cm below the ground surface in the south-east of the Ghab.

It should be mentioned here that the drainage intensity based on the above-mentioned drainage criteria is more than sufficient to maintain a favourable salt balance in the soil under the Ghab climatic conditions. It is also quite satisfactory to control the fluctuation of underground water table which will be caused by the high irrigation losses, mentioned before, within safe limits for the development of agricultural crops. This is understandable for several reasons: firstly, the irrigation water available during the summer months is only sufficient for half the area; secondly, the irrigated area is not concentrated in very large blocks due to the fact that the size of the individual holdings is only about 2.5 ha. Thirdly, in addition to this, the irrigation cycle extends for about 3 weeks. Furthermore, this has also been confirmed by field observations of underground water levels and discharges of field drains for four irrigation seasons, in light organic calcareous soils at Ain El Naour Drainage Experimental Farm.

8.5.3.3 The hydrological properties of the soil profile

In the case of the organic calcareous soils, the top soil profile of about 2.5 metres deep has an average permeability of 12.0 m/day. Below this, the marly formation starts (grey plastic marl) with very low permeability of about 10 to 20 cm/day. For practical purposes this marly formation, which extends for several hundred metres, can be considered impermeable.

Regarding the marly soil, the top soil profile of about 2.0 metres thickness has an average permeability of about 10 m/day. Like the above soil type, the grey marly formation starts at about this depth

8.5.3.4 The formula to be used in calculating drain spacing

It was found that the steady state flow formula of Hooghoudt gives very satisfactory results and corresponds well with the drainage experimental results. This formula is as follows:

$$L^2 = \frac{8K_2dh}{q} + \frac{4K_1 h^2}{q}$$

Where:

- L = Drain spacing in metres
- q = Drain discharge in metres per day
- k₁ = Hydraulic conductivity of the soil layer above the drains in m/day
- k₂ = Hydraulic conductivity of the soil layer below the drains in m/day
- h = The height of the water table above the drain level midway between the drains in metres
- d = Thickness of the equivalent layer. This depends on the drain spacing (L), the drain radius "r" and the depth of the impermeable layer "D" below the bottom of the drains in metres. Under the Ghab conditions, the value of "d" is nearly equal to "D". See paragraph 8.5.3.5. later on.

Visser's formula was also used and gave nearly the same figures obtained by Hooghoudt's formula. The Visser formula applicable to the Ghab conditions is the following:

$$h = \frac{qL^2}{-8K_1 D_1} + \frac{qL}{\pi K_1} \ln \frac{D_0}{u}$$

- 1 : h, q, L and K are the same as those mentioned above in Hooghoudt formula
- 2 : D₀ = The depth of the impermeable layer below the water level in the drain in metres
- 3 : D₁ = D₀ + 0.5h
- 4 : Ln = Natural Logarithm (e)
- 5 : u = The wet perimeter of the drain in metres
- 6 : π = 3.14

8.5.3.5 Summary

It is now possible to calculate the drain spacing after deciding on the drainage criteria, the soil hydrological properties and the depth of the field drains. The following Table 3 summarizes all the parameters which should be used in the Hooghoudt formula to calculate the field drain spacing for the calcareous soil groups in the south-

east and north-west of the Ghab. The depth of the permeable top soil above the impermeable dark grey marl has to be found by investigation in the field. The calculated drain spacing in the following table is based on the depths of 2.5 m and 2.0 m for the organic calcareous and marly soils respectively.

Table 3.

| Parameters | Soil Drainage Group | |
|---|---------------------|----------------|
| | Organic Calcareous | Marly |
| 1. Average depth of impermeable layer-m | + 2.5 - 2.5 | + 2.0 - 2.0 |
| 2. Permeability of the top soils profile m/day (K) | 12.0 | 10.0 |
| 3. Depth of field drain-m | 1.3 | 1.3 |
| 4. Depth of Decatering Zone-m | 0.5 | 0.5 |
| 5. Head of water (h) in m | 0.8 | 0.8 |
| 6. Approximate value of "d"-m | 1.18 | 0.70 |
| 7. Drainage runoff (q) in mm/day | | |
| i. South-east of the Ghab | 6 | 6 |
| ii. North-west of the Ghab | 8 | 8 |
| 8. Calculated Drain Spacing in Metres (Hooghoudt formula) | | |
| i. South-east of the Ghab | 140 | 110 |
| ii. North-west of the Ghab | 125 | 95 |

From the above table, it could be noted that with field drain depth of 130 cm the spacing of field drains in the organic calcareous soil and marly soil is 140 and 110 metres respectively in the south-east of the Ghab. In the north-west, where rainfall is heavier, the spacing dropped to 125 m and 95 m for the organic calcareous soils and marly soils respectively.

8.5.4 Types of field and collector drains

Drains can be either of the open or covered type. From the functional point of view, there is very little to choose between open drains and well constructed covered drains. Hence, the choice of using one type or the other is governed by economical and practical considerations which can be summarized as follows

1) It is generally an accepted fact that the main objection to the use of covered drains as opposed to open drains is the higher construction cost of the first. In view of the recent developments in the construction of covered drains by using tile making machines and tile laying machines, this point is no longer an accepted fact. Under the prevailing conditions in the Ghab Valley in Syria, the cost of covered field drains, using machine made concrete tiles of 10 cm inside diameter, and a tile laying machine, is less than cost if the same drains were made open type with the proper side slopes.

2) Other points are all in favour of covered drains as opposed to open drains. The covered drains are much cheaper to maintain. Experience in different countries has shown that the maintenance cost of covered drains is only 20 to 40% of that of open drains. The maintenance problem of the open drains under the Ghab project is a big one. Beside the usual sedimentation and the growth of weed, there is the problem of wind blown light material. This is not to speak of the erosion caused by rainwater and excess irrigation water which erode the sides of the open drains. Blocking the drains by earth to make crossing for human beings, animals and even cars and agricultural machinery is still another administrative and maintenance problem.

3) By the use of covered field and collector drains about 5 to 10% of the surface area, which is the best drained land, will be saved for agricultural purposes. To this one has to add that with covered drains it will be possible to have larger fields and hence a better utilization of the mechanization possibilities. The problem of crossings for field roads and also for irrigation water courses will not arise in case of the use of covered drainage which will mean a further saving in the project construction cost.

4) The possibility of having a breeding place for malaria mosquitoes in the open water courses, especially if they are not well maintained, is still another point against open drains. However, it must be mentioned here that the operation and maintenance of covered drainage system, requires more qualified staff than that required for the open drainage system, so as to be able to observe points of failure which are covered and to locate such points and to put them right. It is quite easy, however, for such a job to be done by a drainage engineer or even by secondary school graduates after a few months training.

5) To maximise the efficient use of irrigation water, it is possible by the manipulation of the water in drain ditches to raise and lower the water table level in the fields. This practise could be carried out with great care in case of occasional shortages of surface irrigation water. The covered system of drainage network in most cases will be more convenient for this purpose than the open drainage system.

Because of the above reasoning, it has been decided that field and collector drains in the Ghab are to be constructed of the covered type.

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by

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Honourable delegates, it gives me a great pleasure to talk to you on the subject of reclamation and management of calcareous soils in Egypt. As a matter of fact, land reclamation activities in this country include the reclamation of salt affected soils, sandy soils and calcareous soils and I am going to confine my lecture to the last one.

9.1. Definition

Calcareous soils, as we define them, are those soils containing amounts of calcium carbonate to affect distinctly the soil properties related to plant growth, whether they are physical, such as the soil-water relations, and crusting, or chemical such as the availability of plant nutrients.

9.2. Distribution

The calcareous soils which are under reclamation are mainly found to the west of the Nile Delta in a strip extending from Alexandria to Lybia. The soils along the Mediterranean Sea coast are formed as a result of wave and wind action. They have the specific characteristics of Oolitic sand dunes. The lime content may reach up to 95 per cent. Due to the wave action, these dunes are pushed inland to form ridges that solidify to various degrees as a result of rainfall, solution and redistribution of carbonates. These ridges, upon weathering, form calcareous soils which are transported by water or wind to the internal ridges and plateau until they connect with the Delta. Consequently, the lime content gradually decreases from 95% along the coast to 4% in the Delta. Although the Delta soils contain 3 to 4 per cent CaCO_3 , we do not refer to them as calcareous soils since no specific effect is noticed on their physical or chemical properties due to CaCO_3 . Generally, the CaCO_3 content of the Egyptian calcareous soils under reclamation varies between 10 to 90% but mostly between 10 and 50%.

9.3. Morphologic Characteristics

The morphology as well as other characteristics of these soils are functions of topography and micro-relief. The topographic features of the area start with the sea coast followed by two ridges with a depression in between and finally a plateau extending to the Nile Delta. Taking this into account, knowing that the soils are mostly residual, and considering the effective soil forming factors in this region, we find that soil erosion, firstly by water and secondly by wind, is the main effective factor leading to the formation of different soils. On this basis, it is possible to classify these soils into three main categories according to depth of profile, percentage of CaCO_3 , and depth to the calcium carbonate horizon and its thickness.

The soils on the ridges are shallow and have no definite horizons. The depth of the profile may be zero, where the surface is eroded by wind, or may reach up to 50 cm. The profiles of the medium deep soils vary from 50 to 100 cm while those of the deep ones are greater than 100 cm. The variation in the soil depth between these three categories is gradual and no definite boundaries exist between them. The formation of this toposequence repeats itself all over the area from the deep soils at the centre of the depressions to the shallow soils on the top of the ridges.

From the stand point of the lime horizon and lime content, we find that the soils on the ridges have no definite lime horizon but the lime content is usually much higher than in medium or deep soils. The lime horizon of the medium deep soils is generally close to the surface and generally does not exceed 20 or 30 cm. In some cases, it may be clearly defined and in others diffused. In the deep soils, the lime content is generally less throughout and two types of profiles can be identified; in the first, a clearly defined horizon is found diffused in a layer that may reach 30 cm thick and in the second type the lime accumulation horizon may not be clear at all. It has been found that the formation of the lime horizon is related to the micro-relief, the moisture relations and the soil permeability. In areas where the accumulated amount of rainfall is large and the permeability is high the lime horizon does not show itself. But if the internal water movement is limited, due to low permeability and surface runoff as affected by the micro-relief, then the accumulation horizon becomes well defined.

The texture of these soils is usually coarse on top of the ridges and becomes finer as we move downward to the depressions.

In some of these soils, a gypsum hardpan may be formed at the bottom of the depressions. The origin of this gypsiferous horizon may be pedologic or geologic and its depth varies with the water and salt movement depending upon whether it results from the groundwater or the reaction with sea water.

From intensive studies on the clay minerals of the calcareous soils in this region we have found that the dominant mineral is attapulgite mixed with a small amount of kaolinite and montmorillonite.

9.4. Reclamation and Management

A detailed soil survey, prior to reclamation, was carried out by various institutions (the Desert Institute, the Land Reclamation and Development Institute, the Soils Department of the Ministry of Agriculture and the High Dam Authority). The soils are mainly calcareous loams and in part of the area they are calcareous sand at least in the surface horizon. In those soils covered with sand, the subsoil is quite similar to that of calcareous loamy soils. These soils have been subjected to submergence by sea water and have similar characteristics and type of clay minerals as those previously mentioned.

Since our experience in reclaiming calcareous soils was rather limited, we started with studies on their water relations, fertility and chemical characteristics.

9.4.1 Soil water relationship

The soil water relationship was the first problem faced but through intensive research we were able to learn more about the behaviour of these soils under irrigation. The available moisture range is not more than 10 to 12% as an average. Wilting occurs at 9 to 10%, while the field capacity is 19 to 21%. Comparing these soils with the clay soils of the Delta we find in the latter that wilting occurs at about 16%, the field capacity is about 36 to 37% and the available moisture range is about 23%. From various studies it has been found that most of the available water is utilized before or even at a moisture tension of one atmosphere, while in the Delta soils this may occur at a tension of 4 atm.

Since most of the lime is in the silt fraction, one would expect that the ability of these soils to retain moisture would be rather limited. The studies have revealed that most of the water is being held by physical forces and that is why the decrease in the available moisture occurs rather abruptly and not gradually as is the case in the alluvial soils of the Delta. Of course, these moisture characteristics are very much related to the efficiency and frequency of irrigation.

9.4.2 Surface crusting

Another basic problem was that of surface crusting. It is known that the organic matter content of these soils is not more than 0.4% and it is usually much less than this. Before putting these soils under irrigation for the first time they possess apparent good physical conditions, but as soon as they are irrigated chemical changes occur. Solution of carbonates to bicarbonates and the precipitation of the latter upon drying assist in the formation of a hard surface crust which is also affected by the texture and the dominance of other salts beside the CaCO_3 . In the presence of Na salts the formation of this crust is not so obvious and it breaks off easily. Its thickness may vary from a few centimetres to more than 20 cm in some cases. Since crusting was one of the main problems that faced agriculture, especially in the early stages of development, studies were carried out on soil, water and crop management practices to reduce the effect of this phenomenon.

9.4.3 Land levelling

Land levelling was a third major problem that we were faced with in reclaiming these soils. The topography is not flat as is the case in the alluvial soils but is mostly undulating with a slope which may sometimes reach 5%. Because the slope does not follow a single direction, putting these soils under irrigation would require their levelling in a certain direction. How can this be done without ruining the soil properties and in particular without removing the top surface, which may be relatively highly fertile or exposing the lime horizon to the surface, which is the worst thing that can be done.

Studies have been undertaken to find out the appropriate methods of irrigation, dimensions of the plots, surface slopes and degree of levelling. No general specifications could be worked out but the specific nature of these soils had to be taken into consideration. A detailed soil survey could be very helpful in this regard and a scale of 1:2 500 is the most appropriate. It is worth mentioning that the inaccuracy of land levelling has led to numerous mistakes in our utilization of these soils.

9.4.4 Irrigation methods

The selection of an appropriate irrigation method was the fourth problem. Egyptian farmers are used to surface flooding irrigation of their flat and extensive lands without harmful effects to their soils when supplied with adequate drainage. But for the newly reclaimed calcareous soils which are characterized by the previously described topographic features and by the difficulty in levelling them, a more suitable method of irrigation must be found.

Taking these limitations into consideration, contour irrigation could have been appropriate for these soils. The method was applied on an experimental basis and it was possible to determine the design criteria such as the length of run, slope and rate of discharge to give the best moisture distribution in the root zone along the length of run. Unfortunately, the contour irrigation method as well as contour farming, both being new to the Egyptian farmer, were not easily accepted for application. The method was modified and the land was levelled. Consequently, problems of secondary salinization and low irrigation efficiency became apparent.

In fact, contour cultivation could and should have been generally used in this area since it had been practised by the Romans under rainfed agriculture where the rainfall was collected in the depressions for winter crops and the soil fertility was kept high.

9.4.5 Soil cultivation

The methods of soil cultivation adopted differ from those practised in the Delta soils which are homogenous, low in carbonate content, have higher amounts of organic matter and a physical condition which is favourable for root extension. The calcareous soils quickly change their favourable properties when irrigated. They become indurated and resistant to root penetration especially in that portion of the profile subjected to wetting and drying. Therefore, the depth of ploughing is one of the important factors in relation to the success or failure of growing crops.

Different ploughing techniques and ploughs were tried. The results indicate that the optimum depth should not be less than 20 cm, and preferably 25 cm, using a mouldboard plough followed by a chisel plough in a perpendicular direction. The moisture content at the time of ploughing should be adequate in the ploughing depth to ensure a good soil structure. It has been found that the optimum moisture range for ploughing is very narrow and occurs within 4 to 5 days of irrigation, but after 7 or 8 days ploughing becomes difficult. Therefore for the successful ploughing of these soils it is essential that it should be carried out within a short time. Unfortunately, it is rather frequent that a lack of awareness of these principles leads to serious problems.

9.4.6 Suitable crops

The classical crops grown on the Delta soils such as cotton, wheat, maize and sugar cane, were the first it was thought of growing on the calcareous soils but all failed except maize. Cotton failed to grow on these soils because of physical, chemical and nutritional factors and even the normal morphology of the plant changed and became different from the Egyptian cotton. We have to think of lime-loving plants and for this reason legumes occupied first priority (alfalfa, Egyptian clover, peas and beans). Beans did not succeed as well as could have been desired due to the effect of wind and other environmental factors. At least alfalfa and other kinds of berseem proved to be successful. That is why they occupy about 33% of the cropping pattern on these soils. But the main problem of these crops is their high water requirements and the subsequent secondary salinization in the low lying fields.

To avoid the problems arising from high water applications, we have had to think of other lime-loving crops which require less water. From experience, we have found that vines satisfy these requirements (5 000 m³/ha) followed by almonds and olives. Fruit trees occupy 33% of the cropping pattern with vines constituting the main crop on deep soils with no line horizon, and almonds and olives on medium deep soils with a carbonate accumulation horizon. Oil crops, such as sunflower and flax, have grown successfully on these soils and they make up, with some vegetables, the remainder of the cropping pattern. In summary, 33% are occupied with alfalfa, 33% with vines and 33% with oil crops and vegetables.

9.4.7 The nutritional problem

It is known that calcareous soils with a high percentage of CaCO₃ have a pH greater than 8 and may reach 8.6. Thus, deficiency symptoms of most plant nutrients and in particular of phosphorus are expected to appear on almost all crops. Up to the present, no proper technique has been found to ensure a continuous supply of this nutrient to the

plant. The application of the practice adopted for the Delta soils, where medium amounts of phosphorus are applied to legumes, has not given satisfactory results on the calcareous soils. It is essential to adopt the concept of initial concentrated doses of phosphatic fertilizers. A heavy application, sufficient to bring the available phosphorus to a certain level, should be made in the beginning followed by subsequent annual applications to maintain that level. This means that not less than 150 units of P_2O_5 /acre should be applied when the land is first put to cultivation (2 400 kg/ha of superphosphate).

I think that it is due to the incorrect programmes for phosphatic fertilization that crop yields are lower than expected. Wheat for example can attain a good vegetative growth but grains do not reach the proper size.

The micronutrients are all deficient and detailed studies are needed to ensure proper application using new techniques such as spraying.

Nitrogenous fertilization does not pose a problem. The reaction of lime with ammonia is known and Egyptian scientists have studied the nitrogen problem and have made specific recommendations.

9.5. Conclusion

In conclusion, I would say that these are some of the main problems of the reclamation and management of calcareous soils in Egypt. I would like to draw your attention to the problem of secondary salinization which, to a great extent, is related to profile characteristics and water seepage. The engineering design of irrigation canals should be considered carefully when planning irrigation networks to avoid water seepage especially from higher ditches to adjacent low lands. The problem of salinity in the presence of $CaCO_3$ is worth further investigation.

I thank you for your attention.

PROBLEMS OF REGIONAL INTEREST AND SUGGESTED
RESEARCH PROGRAMMES FOR CALCAREOUS SOILS

by

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The suggested research programmes should aim at providing results that would contribute to advances and practical application in reclamation, improvement and management of calcareous soils in the Region. To give this wide ranged subject-matter and its inter-relationships its due of comprehensive coverage would require involvement in unnecessary extraneous detail. This paper, therefore, attempts at indicating a number of salient research topics and lines of work from which might be selected a future course of action in formulating a research programme of practical significance.

10.2. Research Problems and Priorities under the Subject of Reclamation, Improvement and Management of Calcareous SoilsA. Research Problems

- (a) Classification of calcareous soils into groups of mapping unit associations and series and the correlation of soil behaviour with soil characteristics. Parameters such as depth of profile; CaCO_3 content, its textural fraction form and distribution; amount of organic matter, soil texture, structural stability and parent material may be taken as criteria for classification;
- (b) Methods of land preparation for irrigated farming (levelling, contour farming);
- (c) Fertility build-up and inter-relationships with calcium carbonate, (green manuring, farm manures, legume cropping; application of fertilizers, types of fertilizers and methods of application; especially micro-nutrients);
- (d) Tillage practices in relation to soil structure stability and soil erosion;
- (e) Soil crusting especially the early stages of soil reclamation and development (water management, organic matter and synthetic compounds, heavy seeding, use of spikes etc.);
- (f) Improvement and management of irrigation methods, frequencies and practices (soil moisture characteristics, available moisture range, light versus heavy irrigation, new irrigation methods);

- (g) Secondary soil salinization under calcareous conditions (rate of upward water movement and salts under different soil, crop and climatic conditions); alternative systems for the reclamation, improvement and management of these soils;
- (h) Selection of suitable crops, crop varieties and root stocks with lime tolerant qualities;
- (i) Drainage requirement for the control of water table of soil salinity.

B. Priorities

- (a) Soil fertility problems; application of phosphate and micro-nutrients; addition of organic matter;
- (b) Soil and water management practices; tillage practices to minimize crusting problems; soil erosion by wind and water; irrigation methods and schedules;
- (c) Selection of suitable crops, crop varieties and rootstocks of fruit trees with lime-tolerant characteristics.

10.3. Possible Lines of Activities and Research on Calcareous Soils

(1) Soil Survey

An attempt should be made to classify calcareous soils in terms of their relative capacity (or effect) to induce chlorosis in major field and horticultural crops and in relation to their relative inducement of adverse soil and crop physico-chemical and biochemical conditions.

(2) Soil Physics

- Improvement of soil structure;
- Amelioration of surface crust conditions;
- Range of optimum soil-water relations;
- Effect of the textural fraction of CaCO_3 particles upon reducing chlorosis in crops.

(3) Soil Chemistry

The system $\text{CaCO}_3 - \text{pH} - \text{HCO}_2 - \text{CO}_3 - \text{H}_2\text{O}$ has to be studied in terms of all possible permutations of these variants and their relationships under controlled environmental conditions.

(4) Soil Microbiology

- Legume inoculation for improving Nitrogen-fixation;
- Effect of organic manure;
- Action of the beneficial microflora upon lime-induced chlorosis.

(5) Soil Fertility and Plant Nutrition

- The N.P.K.: time of application, form and type of fertilizer, placement and rates of application;
- Phosphorus availability, PK interaction in calcareous soils; micro-nutrients, pH;
- Comparing tolerant with sensitive variety and strains of crops in relation to calcareous soils;
- Use of lyophilization (fast freezing) in identifying the metabolite of the lime-induced chlorosis condition of the growing crop or plant;
- Translocation of nutrients, antagonism between elements with special reference to Ca⁺⁺, K⁺ etc. (Ref. A. Khatib);
- Minor element deficiencies; foliar application of nutrients, chelating agents to control chlorosis (application to dry farming versus irrigated conditions). (Ref. work of Dr. A. Mattar - Syrian Arab Republic).
- Physiologic and genetic facets of crop tolerance to lime-induced chlorosis, criteria of soil classification.

(6) Clay Mineralogy

- Effect of the clay mineral constituents upon the incidence of chlorosis in calcareous soils;
- Identification of the clay mineral fraction of calcareous soils;
- Varying the specific surface areas of CaCO₃ particles in calcareous soils.

10.4. Proposed Approach for Attempting Solutions of Calcareous Soils Problems

To realize effective solutions to the field problems of calcareous soils, it is necessary that a concerted cooperative and regional approach be taken by the countries of the Near East along the following course of action:

- (1) Delineation through soil survey of calcareous soil areas that are acutely afflicted with the problems of lime-induced chlorosis. This field study is to be combined with a detailed characterization of the soils of these areas.
- (2) Establishment of representative Pilot Experiment Areas for the conduct of laboratory/greenhouse/field experimentation on: (i) multivariant single or double factor experiments; (ii) multivariant multifactor experiments. The subject-matter of this programme may be selected from the relevant facets of soil physics, soil chemistry, soil microbiology, soil fertility, plant nutrition and clay mineralogy. As an integral part of this approach, field experiments on the following factors are proposed: Cultural Practices, Crops and Cropping Patterns; Irrigation and Drainage Practices, Amendment and Fertilizer Applications.
- (3) Establishment of Representative Pilot Development areas on land and water use of calcareous soils for which a cropping pattern of relevance to the local rural community be implemented. Account has to be taken in this respect to apply the pertinent reclamation, improvement and management practices for

calcareous soils. Since these field operations have to be carried out on profitable agricultural production economic grounds, it is imperative to keep the input/output record of the major field operations. This information has to be duly analysed and interpreted in terms of the criteria for realizing economic profitability.

- (4) Collection, review, analysis and dissemination of the literature on relevant problems of calcareous soils published in the countries where progress has been achieved in this line of action.

PROGRESS REPORT ON
THE REGIONAL APPLIED RESEARCH PROGRAMME ON
LAND AND WATER USE IN THE NEAR EAST

by

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11.1. A BRIEF REVIEW OF THE APPLIED RESEARCH PROGRAMME FOR THE NEAR EAST REGION

1.1. Introduction

The countries of the Region are realizing more and more the serious impact of problem soils and of poor water management upon their agricultural production economy and upon the social welfare of the rural population. Serious efforts and measures are being taken by these countries in collaboration with FAO to determine practical solutions for improving this situation. The support of the countries for the Regional Applied Research Programme for Efficient Use of Land and Water is a testimony to this trend.

The Regional Applied Research Programme has so far been handled, from the FAO side, as a small scale Technical-Assistance-type Project (TA). The current transition from the status of a small-scale TA-type project to the status of a large-scale Regional Project has been associated from both FAO and the Near East Regional Commission on Land and Water Use with a very active preparatory phase.

At present, the Regional Programme is at its preliminary implementation stage. The Commission recommended to the Governments, during its Third Session (December 1971) that they take necessary steps to implement their share of the Regional Applied Research Programme for 1972-73. It is hoped that the full-fledged larger-scale operations will be launched by January 1973 pending the approval of the Regional Project by UNDP.

1.2. Phases

The main landmarks during the preparatory phase of the Regional Applied Research Programme on Land and Water Use consisted of: three Near East Regional Seminars; an Ad Hoc Consultation; three Sessions of the Near East Regional Commission on Land and Water Use; a three-month consultant's mission; and several missions of FAO Land and Water Officers to the various countries in the region. The preparatory phase covered the following aspects:

- (a) The establishment of the Regional Commission, as a Statutory Body of FAO, by the FAO Council during its 46th Session in 1966. One of the major objectives was to assess priorities for the elimination of factors limiting efficient land and water use in the Region.

- (b) The Regional Seminar on Land and Water Use in the Near East, Beirut, September 1967 where Technical Problems of Water Use in Agriculture and of Land Use Planning in the Near East were discussed.
- (c) The First Session of the Regional Commission on Land and Water Use in the Near East, Beirut, September 1967 which proposed the establishment of the National Land and Water Use Committees and defined their functions.
- (d) The Ad Hoc Consultation to Review the UNDP/FAO Land and Water Use Projects in the Near East, Amman, May 1969. Fifteen possible subjects for a Regional Applied Research Programme were identified and the methodology to tackle them was outlined. The establishment of a Regional Applied Research Programme was proposed.
- (e) The Second Session of the Regional Commission on Land and Water Use in the Near East, Cairo, September-October 1969. The Commission recommended to the Governments of all Member Nations of the Region and to the FAO Director-General to establish and initiate the implementation of the Regional Applied Research Programme. First priority was given to problems considered of most immediate concern to the Region, namely:
 - Reclamation, improvement and management of:
 - (i) salt affected and waterlogged soils;
 - (ii) calcareous soils;
 - (iii) sandy soils; and
 - Efficient use of irrigation water, taking into account crops, cropping patterns and the efficiency of irrigation methods.
- (f) The 10th FAO Regional Conference for the Near East, Islamabad, September 1970, accorded high priority to the Regional Applied Research Programme on Land and Water Use.
- (g) The collection of information on the applied research situation in Land and Water Use from Member Countries through FAO and UNDP Country Representatives and Experts on FAO/SF projects.
- (h) The Regional Seminar on Methods of Amelioration of Saline and Waterlogged Soils, Baghdad, December 1970. A brief preliminary review on the situation of applied research in Land and Water in the Region was presented. The need for standardized methodology and data systematization was recognized by the specialized government agencies.
- (i) The three-month Consultant's mission (December 1970-February 1971) to visit the countries in the Region and investigate the research situation in relation to the Regional Applied Research Programme. A plan of work was delineated by the Consultant (Rafiq) in collaboration with the FAO Land and Water Officers. The Consultant's report entitled "Regional Applied Research Programme - An Evaluation of the Present Situation and Proposals for Action" was distributed to Governments in the Region in August 1971.

An important finding reported was the following: Among the 67 institutions surveyed in 18 countries in the Region: (i) 38 are tackling problems related to salt affected and waterlogged soils; (ii) 36 are carrying out applied research on effective use of irrigation water; (iii) 23 are working on calcareous soils; and (iv) only 8 are engaged in reclamation, improvement and management of sandy soils.

- (j) The Regional FAO/UNDP Seminar on Effective Use of Irrigation Water at the Farm Level, Damascus, December 1971, emphasized that correct determination of water requirements of irrigated crops is essential for project planning and operation. A common methodology was recommended to facilitate the comparison of results. Inter-disciplinary cooperation for land reclamation and land and water management was also emphasized since lack of adequate field drainage and inadequate water applications are the main causes of re-salinization after reclamation. Background papers dealt with investigations on: (i) the existing salinity and sodicity classification limits under the Near East conditions; (ii) the optimum water table depth for drainage design on an economic basis; (iii) the hydraulic soils' characteristics for design of drainage systems; (iv) the crop water requirements; and (v) the sampling, analysing and mapping of salt affected soils. Within the context of the four priority lines of action of the Regional Applied Research Programme, the following objectives for the Regional programme were endorsed:
- (1) To disseminate to countries of the Region information on the currently active applied research centres. This information covers the programme of work, names of research and technical workers, their fields of specialization and their research and technical accomplishments.
 - (2) To assist in determining uniform technical criteria and standards for field problem identification, methodologies of field survey and investigation and technical field development operations.
 - (3) To assist in establishing field experimental programmes and work plans for pilot project areas at the country, sub-regional and regional levels. The findings of these and other technical activities will be cumulated in a central soil data bank for analysis and retrieval.
 - (4) To assist in the review and development of the technical programme of work of the applied research centres in the countries of the Region.
 - (5) To assist in determining a system for cooperative and complementary coordinative working relationships between the applied research centres which work on problems of common interest in the countries of the Region.
 - (6) To assist in inducing a system for developing cooperative and coordinative relationships between the applied research workers and technicians who are attached to inter-related sectorial government services namely: applied research, education, extension and pilot project area operations.
 - (7) To assist in initiating and/or strengthening training centres for the technologic training of technicians at the country, sub-regional and regional levels.
- (k) The Third Session of the Regional Commission on Land and Water Use in the Near East, Damascus, December 1971, advised starting on two lines of action for the Regional Applied Research Programme. The Commission agreed to give priorities to 3 experiments: (i) Reclamation of salt affected soils; (ii) Management of leached soils; and (iii) Crop water requirements. Guidelines and experimental layouts, prepared by FAO consultants or officers, were given for consideration by the Commission. The Commission indicated that time is needed for their study and evaluation on a regional basis; comments should be forwarded to the prospective authors who will report during the next regional seminar. On the other hand, the Commission recommended integrated type experiments taking into account the crop production factors. The Commission urged the Member Countries to submit their comments after testing the guide-

lines for sampling, analysing and mapping of salt affected soils. Finally, it supported and endorsed the draft request for a 5-year Regional Applied Research Project (1973-1977).

- (l) The Guidelines and experimental layouts on (i) leaching of soluble salts; (ii) management of salt affected soils; and (iii) crop water requirements, including the variants and factors agreed upon by the Commission, were distributed in February 1972 to the countries in the Region, for remarks and comments.
- (m) The three-man mission to Iraq, Syria, Jordan, Lebanon, Sudan and the Arab Republic of Egypt, 30 January-22 February 1972, clarified the purpose of the Regional Project, the Governments and UNDP Contributions.
- (n) The Regional Project for Applied Research on Land and Water Use was endorsed by eleven countries in the Region. This five-year project aims at the establishment and support of a coordinated regional programme for applied research in four priority lines of action listed under (e) above. Its main role would consist in the standardization of the research methodology, initiation of a regional approach to the problems, coordination of the applied research activities, assistance in the exchange of information within the Region and education and training of technicians and field staff in irrigation, drainage and land reclamation.
- (o) The recent missions to the countries by the Regional Land and Water (TA) Officers. The 3 guidelines were presented to the specialists and research workers for comments and eventual implementation of the experiments in 1972-73. Issues and factors affected by local conditions, such as crops, crop rotations, fertilizer levels and agricultural calendar for field operations were discussed and agreed upon in most cases. The seven participating countries (Egypt, Iraq, Iran, Jordan, Lebanon, Sudan ^{1/}, Syria) and two supporting (Cyprus and Kuwait) were visited in 1972. Detailed reports were written on their situation and progress (See References).
- (p) A consensus was reached by the Eleventh Near East Regional Conference (Kuwait September 1972) on according first priority to the Regional Applied Research Programme for Land and Water Use in the Near East.

11.2. PRESENT STATUS IN THE VARIOUS COUNTRIES OF THE REGION

2.1. Agreements Reached at the Third Session of the Regional Commission on Land and Water Use in the Near East

The situation of the applied research in the various countries in relation to the four lines of action of the Regional Project was briefly reviewed during the Baghdad Seminar (December 1970). A more detailed picture was presented in December 1971 (Damascus Seminar and Third Session of the Regional Commission).

During its Third Session, the Commission discussed the situation, needs and possibilities concerning the execution of three experiments (leaching of salt affected and water-logged soils, management of reclaimed soils and crop water requirements). The outcome is summarized in the following Tables (1 and 2).

^{1/} Sudan only was not visited when this report was submitted.

Table 1. Information on the Experimental Sites for Leaching and Management of Salt Affected Soils, Executing Organizations and Officer-in-Charge

| Country | Soil Texture | Climate | Ground-water depth | Irrigation water quality | Soil Salinity Sodicity | Location of Project | Executing Organization | Officers-in-Charge |
|--------------------------------------|--------------------|-----------|---------------------|--------------------------|-------------------------|---------------------------------|--|---|
| <u>Egypt</u> | | | | | | | | |
| A. Leaching and Drainage | Heavy | Semi-arid | Shallow | Good | Saline-Sodic | Hamoul (Lower Delta Med. Coast) | Min. of Agric. and Land Reclamation (Land Dev. and Utiliz. Org.) | Shabassy Anwar Ghaith |
| B. Management of Salt Affected Soils | 1 Med. to Heavy | Semi-arid | Medium to deep | Good | Recl. | Sakha Mid-Delta | Ministry of Agriculture | Shabassy Mitkees Barakat El Nahal |
| | 2 Med./Heavy Calc. | Semi-arid | 5 depths (variable) | 3 qualities | Saline-Sodic | Alex. (Bacos) Salin. Lab. | Ministry of Agriculture | Shabassy Mitkees Barakat El Nahal |
| <u>Iran</u> | | | | | | | | |
| | 1 Med./Heavy | Arid | Shallow | Good | Saline | Ahwaz | Agric. Eng. | Borhan Sanii |
| | 2 Med./Heavy | Arid | Shallow | Good | Saline | Shaur | Soils Institute | Mahdevi Ghazanshahi Tawassali Pazira Shafi |
| | 3 Med./Heavy | Semi-arid | Shallow | Mixing poor with good | Saline | Marvedasht (Shiraz) | Soils' Inst. Min. of Agr. | Mahdevi Sanii Siadat Feili Djawaheri Geisi Khosrari |
| | 4 Med./Heavy | Humid | Shallow | Good | None but heavy sub-soil | Rasht | Soils' Inst. Min. of Agr. | Mahdevi Sanii Siadat Nikmaru Rastegar Asa |

Table 1. Information on the Experimental Sites for Leaching and Management of
(cont.) Salt Affected Soils, Executing Organizations and Officers-in-Charge

| Country | Soil Texture | Climate | Ground-water depth | Irrigation water quality | Soil Salinity Sodicity | Location of Project | Executing Organization | Officers-in-Charge |
|----------------|----------------|-----------|--------------------|--------------------------|------------------------|---------------------|-------------------------------------|-----------------------------|
| <u>Iraq</u> | 1 Medium | Semi-arid | Shallow | Good | Saline | Radhwaniyeh | Soils and Land Recl. Dept. | Harran |
| | 2 Medium | Semi-arid | Shallow | Good | Saline | Khales (Abbas) | Soils and Land Recl. Dept. | Shamri |
| | 3 Medium | Semi-arid | Shallow | Good | Saline | Khales (Mussari) | Soils and Land Recl. Dept. | Shamri |
| <u>Jordan</u> | 1 Medium | Arid | Deep | Good | Saline-Sodic | Wadi Dhuleil | Dept. of Res. & Ext. | Banna |
| | 2 Heavy | Arid | Deep | Good | Saline-Sodic | El-Hessa | as above | Banna |
| <u>Sudan</u> * | 1 Heavy | Semi-arid | Deep | Good | Non-Saline | Gezira | Agr. Res. Corp. & Soil Survey Dept. | Mukhtar Saleh |
| | 2 Light/Medium | Semi-arid | Deep | Good | Saline-Sodic | Hudeida | as above | Mukhtar Saleh |
| <u>Syria</u> | 1 Medium | Semi-arid | Shallow | Good | Saline | Deir-El-Zor | Dir. of Soils, Min. of Agric. | Matar Saady El Abedine |
| | 2 Light | Semi-arid | Deep | Good | Saline | Raqqa | Min. of Euphrates Dam | Kattan Hassan El Abedine |

*Definitive action not taken pending visit Regional Officers to Sudan 10-20 November 1972.

Table 2. Information on the Experimental Sites for Effective Water Use at the Farm Level Executing Organizations and Officers-in-Charge

| Country | Soil Texture | Salinity | Climate | Crops | Method of Irrigation | Water Quality | Water Table Depth | Location | Executing Organization | Officers-in-Charge |
|---------------|--------------|------------|-----------|---|--------------------------------|----------------|-------------------|------------------------|---|---|
| <u>Cyprus</u> | 1 Med./heavy | Non-saline | Semi-arid | Citrus | Sprinkler | Good | Deep | Morpha Exp. Farm | Agriculture Res. Inst. Dept. of Agr. -Water Use Section | <u>Rapporteur:</u> Director of Agric. Res. <u>Rapporteur:</u> Mr. Nicolaou |
| | 2 Medium | Non-saline | Semi-arid | Alfalfa (spring potatoes) | Sprinkler | Good to saline | Deep | Athalassa Exp. Farm | Agriculture Res. Inst. Dept. of Agr. | Director of Agric. Res. <u>Rapporteur:</u> Mr. Nicolaou |
| <u>Egypt</u> | 1 Med./heavy | Recl. | Semi-arid | (Horse beans, Wheat and Trefolium Alexandricum (Berseem)) | Basin | Good | Medium/Shallow | Sakha (N. Mid-Delta) | Ministry of Agriculture | Shabassy Farrag |
| | 2 Heavy | Recl. | Semi-arid | | Basin | Good | Deep | Jemeza (N. Delta) | | |
| | 3 Medium | Recl. | Semi-arid | | Basin | Good | Deep | Bahteem (S. Delta) | & | |
| | 4 Medium | Recl. | Arid | (Lentils and Sugar Cane) | Basin | Good | Deep | Mallawi (Middle Egypt) | Ministry of Irrigation | El-Gebaly El-Ghamry |
| | 5 Medium | Recl. | Arid | | Basin | Good | Deep | Mataana (Upper Egypt) | | |
| <u>Iran</u> | 1 Medium | Non-saline | Semi-arid | Sugar-beet Wheat Alfalfa | Furrows Border Sprinkler | Good | Deep | Karaj | Agriculture Eng. Dept. | Borhan |
| | 2 Medium | Saline | Semi-arid | Sugar-beet Wheat Alfalfa | Furrows Border Sprinkler | Good | Deep | Shiraz (Marvedasht) | Soils Inst. and University of Pahlevi | Mahdevi Sanii Siadat Feili Geisi Khosravi |

Table 2. Information on the Experimental Sites for Effective Water Use at the Farm Level
(cont'd) Executing Organizations and Officers-in-Charge

| Country | Soil Texture | Salinity | Climate | Crops | Method of Irrigation | Water Quality | Water Table Depth | Location | Executing Organization | Officers-in-Charge |
|----------------|--------------|------------|------------|---|---|---------------|-------------------|------------|---|-----------------------------|
| <u>Iraq</u> | 1 Medium | Saline | Semi-arid | Wheat Cotton | Border Furrows | Good | Medium | Abu-Ghraib | Applied Res. on Natural Resources Inst. & College of Agric. | Kawwaz |
| | 2 Medium | Saline | Semi-arid | Cotton Corn Alfalfa | - | Good | Medium | Mussayib | Greater Mussayib Project, Min. of Agrarian Reform | & Nakshbandi |
| <u>Jordan</u> | 1 Medium | Non-saline | Arid | Alfalfa Barley Sorghum | Sprinkler Furrow Border Basin | Good | Deep | Quatrana | Ministry of Agriculture | Hani |
| <u>Lebanon</u> | 1 Med./heavy | Non-saline | Semi-humid | Alfalfa Wheat Sugar-beet Potato | Basin Sprinkler Drip Short Furrows | Good | Deep | Bekaa | Agriculture Res. Station | Sarraff |
| | 2 Heavy | Non-saline | Semi-humid | Alfalfa Wheat Sugar-beet Potato Citrus Ground-nuts | Basin Sprinkler Drip Short Furrows | Good | Deep | Abde | Agriculture Res. Inst. Abde | Sarraff |
| <u>Sudan*</u> | 1 Heavy | Non-saline | Semi-arid | Cotton Wheat Sorghum Ground-nuts | Basin | Good | Deep | Gezira | Agriculture Res. Corp. & Soil Survey Dept. | Mukhtar Saleh Osman Awad |

*Definitive action to be taken pending visit of Regional Officers to Sudan 10-20 November 1972

**Table 2. Information on the Experimental Sites for Effective Water Use at the Farm Level
(cont'd) Executing Organizations and Officers-in-Charge**

| Country | Soil Texture | Salinity | Climate | Crops | Method of Irrigation | Water Quality | Water Table Depth | Location | Executing Organization | Officers-in-Charge |
|----------------|--------------|------------|------------|--|---|---------------|-------------------|-------------|--|--------------------|
| <u>Somalia</u> | 1 Med./heavy | Non-saline | Semi-humid | Sugar-cane | Furrows | Good | Deep | Iowhar | SNAI | Farah |
| | 2 Med./heavy | Non-saline | Semi-humid | Maize Banana | Border Furrows | Good | Deep | Afgoi | Central Res. Exp. Station | Farah |
| <u>Syria</u> | 1 Medium | Non-saline | Arid | Alfalfa Wheat Cotton Sugar-beet | Basin Furrows | Good | Deep | Billanah | Ministry of Euphrates Dam | Kattan Hassan |
| | 2 Med./heavy | Non-saline | Semi-arid | Cotton Alfalfa | Short & long furrows Basin Sprinkler | Good | Deep | Aleppo | College of Agriculture of Aleppo | El Abedine |
| | 3 Medium | Saline | Arid | Cotton | Basin | Good | Deep | Deir-El-Zor | Directorate of Soils, Ministry of Agriculture | Saady Fardawi |

2.1.1 Design and preparation of experiments

Preparation of guidelines and designs by FAO with the help of a statistician for the experiments on leaching and management of salt affected soils and water use efficiency were to be ready by the end of January 1972. The detailed design of experiments were to be submitted directly to the National Committees and the persons responsible for the experiments.

Selection and preparation of sites for experiments by the countries and execution of preparatory work were to take place from January to March.

All soil and water samples, and groundwater level measurements were to be collected prior to sowing which was scheduled from March 1972 onwards.

2.1.2 Types of experiments

Three types of experiments were discussed for a regional approach:

(a) Leaching of virgin, saline soils

The following treatments were to be included:

- Leaching methods: continuous versus intermittent
- Depths and spacings of drains: 3 depths and 3 spacings
- Time of leaching: summer versus winter
- One type of drain - if possible tiled, otherwise open.

(b) Management of reclaimed land

The following treatments were to be included:

- Summer fallow versus non-fallow
- Ploughing during fallow versus non-ploughing
- Fertilizers and amendments, optimum level of fertilizers in the country for the crop versus non-fertilized
- Two water regimes
- Sub-soiling versus non-sub-soiling, in heavy saline or sodic soils as the case in Sudan and Egypt
- Crop rotation: the following rotation has been agreed upon: rice or cotton followed by barley or berseem, fallow or sorghum followed by cotton, barley or berseem followed by rice.

(c) Efficient water use at the farm level

- Irrigation at 4 tension or depletion levels: the normal established practice was to be included as one treatment
- One crop in summer and one in winter, alfalfa is also recommended as a permanent crop. The experimental site should have deep water table whenever possible or tile drainage if needed

- Surface irrigation methods: basin or furrow
- Optimum management practices for the crop in the country should be followed.

2.2. Situation and/or Progress after the Third Session

After the Third Session of the Commission (Damascus 14-18 December 1971), the Regional Land and Water Officers established contacts with the officers in charge of the Regional Applied Research Programme in the various countries of the Region, visited their Research Institutions, Experimental Stations and a number of FAO field projects.

The Regional Officers' Duty Trip Reports cover the details of the discussions and specifications on the methodology of executing the field experimental programmes as outlined in Tables 1 and 2 for each respective country. The following paragraphs cover the salient actions taken by governments and the important constraints and recommendations given by the Regional Officers to the countries concerned during the course of their duty trips.

2.2.1 Arab Republic of Egypt

- 1) During the course of the joint meeting on the new ARE agricultural policy held at the Ministry of Agriculture on 21-22 August 1972, in which participated the senior officials of the Ministry of Agriculture and Land Reclamation and the Regional Officers, His Excellency the Minister, Dr. M. Elgabaly, decided to commission two ARE research officers, one specialized in Soils and the other in Water Management who would be entrusted with the task of surveying and appraising the available ARE literature in their respective fields with particular reference to the four priority lines of action of the Regional Applied Research Programme.
- 2) The FAO Regional Office will recruit the services of a Regional Consultant for two months after December 1972 to survey, appraise and evaluate published and unpublished work of applied research on land and water use in Egypt and the Sudan with special emphasis on applied research in the fields of irrigation and reclamation, improvement and management of salt affected and waterlogged soils.
- 3) Details of the 1972/73 programme were thoroughly discussed during meetings with Drs. Shabassy, Mitkees and Barak and senior staff.

2.2.2 Iraq

- 1) Recommendation that Abu Ghraib Water Requirement Experimental Field becomes a major central site in the country for evapotranspiration and water optimization studies and that supporting work be carried out at Khaled and El Mussayeb.
- 2) Emphasis to be given at El Mussayeb on the evaluation of irrigation method and improvement of water use efficiency under normal size fields.
- 3) Waterlogging is the main water management problem which is accentuating the spread of soil salinization throughout the entire irrigated Raifidain (Mesopotamian) Plain. It is, therefore, crucial that the Government takes urgent measures to check seepage by adopting a policy coupled with an action programme for the lining of irrigation canal networks and the control of water table depth by proper drainage and the control and timing of field irrigation applications.

- 4) Iraq appointed Dr. Kawaz to activate the implementation of the water use experiment.

2.2.3 Jordan

The two consultant reports by Dr. Van den Berg (mission 25/2 to 6/3 1972) stressed the following:

- 1) There is a potential salinization of pumped groundwater by leached salts. A Hydrogeologic survey is necessary to evaluate this condition.
- 2) Land levelling coupled with leaching and control of water losses should be exercised. A sequential system of general field levelling; construction and levelling of basins and borders; first irrigation (200 mm); re-levelling two weeks later; pre-planting irrigation and planting should be exercised. Intermittent leaching should be carried out in the highly salinized areas.
- 3) Gypsum or sulphur amendment application should be investigated for economic justification.
- 4) Sand application ameliorates cultural practices in heavy soils but not infiltration on ESP level.
- 5) Methods of irrigation coupled with economic use of water should be investigated. The following points were stressed by the Regional Officers duty trip reports:
 - The criteria for sound soil/water/crop management have to be derived from integrated field experiments in representative soil mapping areas.
 - For the rational development planning of the country's land and water resources, it is necessary to carry out standard soil survey and classification at an appropriate reconnaissance scale.
 - Concurrently with standard soil survey and classification, the need is also pressing for collecting information on soil fertility survey and agro-climatologic mapping and zonation at the country level.
 - In view of the hazard of waterlogging to which the East Ghor region is exposed, it is recommended to recruit a field drainage expert to investigate the project area's drainage requirements.
- 6) Water requirement experiments and evaluation of surface and sprinkler irrigation methods are advancing at the Quatrana Farm.

2.2.4 Lebanon

- 1) There is a pressing need to take immediate action in starting the operation of the precision weighing lysimeter for the Regional Applied Research Programme. The recruitment of an additional researcher for irrigation is essential.
- 2) Applied research on irrigated calcareous soils at the Lebaa Station should be strongly fostered since varying calcareous soil conditions exist in its vicinity.

3) Bibliographic references were classified and pertinent articles reviewed in the following fields by the Regional Water Management Officer:

- Lysimetry and Measured Potential Evapotranspiration
- Evapotranspiration (ET) Estimates (Formulae)
- Crop Water Use
- Soil Moisture Conditions Plant Growth and ET rates
- Irrigation Control and Guiding
- Irrigation Methods (Evaluation)

4) The advanced state of the applied research work on irrigation and water requirement of crops in Lebanon qualifies it to assume a leadership role in extending the field methodology of this line of the Applied Research action to the countries of the Region through eliciting standardised field application procedures and training of technical personnel. This objective can effectively be realised through the Regional Applied Research Programme for Land and Water Use.

5) The need is crucial to fill the presently vacant posts of soil physics (soil water relationships) and soil microbiology in the Tel Amara Agricultural Experiment Station.

2.2.5 Syrian Arab Republic

1) Standard soil survey of the entire Euphrates project area at the required scale of detail has to be completed.

2) The Regional Applied Research Programme can assist in coordinating, strengthening and, may be, centralizing all research work leading to the efficient use of irrigation water and the reclamation, improvement and management of salt affected, calcareous and gypsiferous soils. A full-time team leader or specialist in water use studies is needed. A close technical collaboration at the planning, implementation, supervision, control and analysis levels is essential at this stage between the subject-matter government offices and Universities.

3) Once the crop and animal systems for the pilot areas of the Euphrates Agricultural Development Project have been determined at the policy administration level, it is recommended that multi-variant test/demonstration field investigations be carried out to determine the outcome of the interactions linking the variants on soils - land preparation and cultural practices - cropping patterns - irrigation and drainage practices - water table conditions and control of soil salinization and fertilizer use. These test demonstrations have to be simplified such that selectivity be exercised in limiting the number of treatment variants to the minimum possible. They are to be carried out at three working levels namely:

(i) In Pilot Field Experimental Areas in association with field experimental layouts that conform with the statistical requisites.

(ii) At the Farmers' Fields in association with the extension service technicians.

(iii) At the Pilot Development Areas on a multi-disciplinary scale in conformity with the locally acceptable concepts of farm management cooperatives the agricultural produce of which is to be prepared for marketing.

4) Immediate implementation of the standardized "Crop Water Requirement Experiments" is recommended at the Billanah Experiment Station (GADEB), at the El Ghab Project (El Ghab Development Authority) and at Douma (Soils Directorate) with the best crop rotations and fertility levels convenient to each site. The lysimeters, meteorological stations or neutron probe available in some of these locations will serve as a starting point. The additional instrumentation and equipment required will be, to a large extent, provided by the Regional Applied Research Project subject to its approval by UNDP.

5) Collaboration with the Arab Arid Zone Centre is recommended.

2.2.6 Other Countries

A. Cyprus

Cyprus is so far a "supporting" and not a "participating" country in the Regional Applied Research Programme. However, it is actively involved in work on efficient control of irrigation applications, on use of low quality waters, and on improved irrigation methods in relation to the associated factors of crop production.

The Water Use Section of the Agricultural Research Institute could be strengthened to provide all the information and measured values on:

- (i) Potential evapotranspiration in the major climatic zones and land use areas of the Island.
- (ii) Net irrigation requirements for the major crops in each area and the recommended irrigation intervals to attain optimization per unit of water applications.
- (iii) Gross irrigation requirements taking into account the efficiency of the irrigation method or of the field water application. This involves the comparison and evaluation of the various irrigation methods (sprinkler, basin, drip, border, furrow) and the field irrigation efficiency.

B. Iran

Both the Soils Institute and the Agricultural Engineering Department are interested in the Applied Research Programme.

- (i) A higher intensity of land use in the rice growing area of Mazandaran Rasht has to be continued through utilizing the winter fallow period by an appropriate crop.
- (ii) In the case of tea culture the outcome of the interaction between irrigation application and fertilizer use increased the yield of tea significantly. Further experimentation should be carried out with a view to determining the combination of irrigation and fertilizer levels which assures the highest economic return.
- (iii) Citrus is being grown so far without irrigation (Guilan area). It is felt that irrigation would raise citrus yield. It is therefore recommended that irrigation combined with fertilizer use experiments on citrus be initiated.

- (iv) The identification and analysis of the clay mineralogical constituents of the clay fractions in soils would contribute to improving the efficiency of fertilizer use - phosphorus in particular. The possibility of identifying institutions in the region willing to cooperate in carrying out clay mineralogic analyses would be investigated by the authors.
- (v) Since the major sources of waterlogging and salinization in the Ahwaz region is the seepage from irrigation canals and misuse of irrigation water the current canal lining action programme being carried out by the Soils Institute should be encouraged and be further expanded. It is also urged to carry out regular waterlogging and soils salinization surveys in all the semi-arid and arid zones of the country in the form of supplementary monitoring activities to the soil survey, land classification and evaluation field operations.
- (vi) It is commendable to note the initiative taken by the Soil Institute in planning the establishment of a pilot development area in the extension sector of the Rasht experiment station. This action will enable the introduction of land and water use production economic criteria to arrive at input/output ratio and economic feasibility assessment of the agricultural areas. This background data is essential for planning development in land and water use as well as in improving the criteria of the systems of land evaluation and land suitability classification. For the purpose of executing this line of action on a sound basis it is necessary to recruit the services of a farm management or an agricultural production economist.
- (vii) Attention is brought to the importance of the recently published articles (see USA Journal of Irrigation and Drainage, Division of the Civil Engineering Proceedings, June, 1972), which covers both the aspect of Potential Evapotranspiration in relation to irrigation design, tolerances and to Soil/Plant/Water Relationships.

2.3. Comments on the Guidelines and Experimental Layouts

Special efforts were made by the Land and Water Regional Officers to collect as many comments as possible on the FAO Guidelines and Experimental Layouts. Viewpoints of specialists and researchers in the various countries are summarized below:

A. Comments on the Guidelines for Crop Water Requirement Experiments

For countries and conditions where salinity and shallow water table are not prevailing, the guidelines were, in general, well accepted. Important points raised and comments made are the following (refer to Guidelines) :

- (i) Under the basic considerations (page 1), crop yield should be mentioned. Answer: the suggested field experiments result actually in yield responses to differential irrigation treatments.
- (ii) The sentence "ample but measured water" (page 4) should be explained. Answer: the amount of water to be applied is equivalent to the crop lysimeter value (no water stress) for the same period. The idea is to wet thoroughly the soil profile in order to allow good root development. Occasional neutron probe measurements are essential to assess the application efficiency and the actual water use under the given irrigation interval as well as the moisture extraction pattern of the crop under the given irrigation treatment.

- (iii) Loss of water by deep percolation in the plots should be assessed. Answer: whenever possible, this laborious and time-consuming assessment should be made. A neutron probe, a number of mercury tensiometers placed at various depths down to 2.50 m, a cropped plot and a bare soil plot are required. Cyprus is undertaking such measurements in collaboration with the IAEA. Results and comments are expected. Meanwhile, it is assumed that internal drainage is significantly reduced 2 to 3 days after irrigation. Correction or refinement of the results is always possible at a later stage.
- (iv) The plot size seems too small. Answer: the plot size suggested should exceed 25 m². Actually, small basins of 25 to 50 m² are most common in the Near East Region. Most countries favoured for crop water use studies sizes of either 50 or 100 m². Larger sizes are suggested for application efficiency and water distribution uniformity studies under various surface irrigation methods (field level).
- (v) More treatments outside the tensiometer range were requested. Answer: water retention (pF) curves and irrigations at 2, 5 and 15 bars are suggested. The soil moisture tension corresponding to actual plant wilting observed early in the morning should be determined and is used, in the guidelines, for the irrigation timing of one treatment. At the end of the experiment, yields versus soil moisture tensions are given. The irrigation intervals along the growing season corresponding to the various tensions should be explicitly given for practical use. In addition to the neutron probe, certain countries asked to introduce the use of psychrometer to measure the soil water potential instead of the metric potential or water content.
- (vi) The precautions essential for obtaining sound data from the lysimeters should be emphasized. Answer: the writer prepared an outline on "Lysimetry and its Use for Crop Water Requirements". It was discussed at the Panel of Experts (Rome, 3-8 September 1972) and the final report will be distributed to countries participating in the Regional Applied Research Programme. For the first year, it is suggested to have two lysimeters under the same crop to assess deviations. Three to four year data are required for each crop.
- (vii) Certain countries, especially Iraq, Iran and Syria are interested in watercrop (population)-fertilizer interactions and economical analysis for optimum crop water requirements under different fertilizer levels. Answer: This could be done by changing the experimental design to split-split plot of factorial and increasing naturally the number of plots.
- (viii) Crops, crop rotations, fertilizer amounts and other treatments affected by local conditions (planting date and harvest ...) should not and/or could not be necessarily the same in all countries. Answer: The Guidelines stress the standardization in methodology and systematization of data and results and provide sufficient flexibility for factors affected by local conditions.
- (ix) In addition to the crop water requirement experiments, Cyprus, Egypt, Iran and other countries are interested in the use of low quality water on non-saline, non-alkali soils with no shallow water table.
- (x) The evaluation of the efficiency of the various irrigation methods at the field level should go parallel to the crop water requirement experiments.

B. Comments on the Guidelines and Experimental Layouts for Reclamation and Management of Salt Affected Soils

- (i) A split-split design was agreed upon instead of the randomized block design for the experiment on management of salt affected soils.
- (ii) It was suggested (Iraq) to conduct the summer fallow versus non-fallow treatments under various groundwater table depths, at least two: one situated within the critical range for resalinization and one below this depth.
- (iii) Crops, crop rotations, fertilizer levels and other factors affected by local conditions should not be rigidly imposed on all countries in the Region; selection of these variants has to be dictated by local conditions and needs.
- (iv) The treatment with no fertilizer was requested to be replaced (Iraq, Egypt, Syria, Iran). Thus two fertilizer levels would be considered. The levels should be specified for each case based on local conditions, soil analysis and previous experience and results.
- (v) The figure of 20% leaching requirement to be applied was argued in certain cases. On the other hand, suggestion was made (Syria, Iran) to include a treatment where the leaching requirement is given in one single application versus the fractionation treatment with 20% each time.
- (vi) The overlap between leaching requirement and irrigation efficiency was often debated.
- (vii) The soil sampling sequence must be unified for both experiments as follows: 0-15, 15-30, 30-60, 60-90, 90-120 and 120-150 cms.
- (viii) The sub-soiling spacing (1 or 2 m) was agreed in relation to soil texture and structure.
- (ix) The number, frequency and extent of soil and water analysis and observations are considered excessive in general. It was requested to reduce them and list the essential ones.
- (x) The two depths of drainage were often questioned.

It was felt that the Guidelines and Experimental Layouts provided an excellent framework for standardization and were well accepted only when tailored to the specific needs of each country, (choice of the crops, crop rotation, fertilizer levels and priorities in the variables and treatments).

2.4. Follow-up Action on the Guidelines and Experimental Layouts

A. Convergence of Efforts in Crop Water Requirement Studies

Improvement of the present guidelines must be a continuous process. The writer - being a member of the Panel of Experts on Crop Water Requirements which pools efforts of Senior Consultants from USA, France, Holland, Lebanon and India - attempts to incorporate the recommendations of this Consultative Group, whenever applicable, to the Region. The first meeting was held at Tel Amara, Lebanon (May, 10-15, 1971) and the second in Rome (3-8 September 1972).

The main items discussed in the Rome meeting were:

- (i) The development of a consolidated approach in determining crop water requirements from formulae using potential evapotranspiration (grass) as a standard reference.
- (ii) Preparation of a guide on agroclimatological instruments and observation practices for use in FAO projects.
- (iii) Preparation of a field manual on measuring and evaluating hydro-physical properties of soils.
- (iv) Preparation of a study on the use of lysimeters in crop water requirement studies.
- (v) Up-dating of the FAO publication entitled "Applied Irrigation Research".
- (vi) Preparation of a comparative study on concepts and methods used in determining the effectiveness of rainfall.
- (vii) Design of a system for storage and retrieval of crop water requirement information.

On the other hand, the International Commission on Irrigation and Drainage (ICID) has established a committee to study the use of lysimeters in consumptive use determination.

Finally, a U.S.A. team (M.V. Jensen and collaborators) started an important work on the same subject.

This concentration of scientific efforts on the crop water requirement at the international level is an excellent backing for this line of action of the Regional Applied Research Programme.

B. Recommendation No. 12 - Third Session of the N.E. Land and Water Use Commission

During its Third Session, the Regional Commission recommended FAO to take the necessary action to establish a bibliography on previous and current research results and publications dealing with land and water use, giving priorities to those undertaken by the Near East Applied Research Programme.

At the country level, the National Committee on Land and Water Use should be more active and assist in providing a complete, true and analysed picture of the land and water research situation. This is particularly essential with respect to Egypt and Sudan due to the large number of institutions and researchers in land and water use. The Regional Office is taking action along this line in collaboration with the Ministry of Agriculture in Egypt.

C. Additional Information

Additional guidelines and a new experimental layout are necessary if salinity, water table, water quality, fertilizer, and water depletion interactions are to be studied in one integrated experiment.

11.3. SUMMARY AND CONCLUSIONS

- (1) The Near East Applied Research Programme for Efficient Land and Water Use has been so far handled as a small Technical-Assistance-type project. The switch from small-scale TA-type to a large-scale Regional Project has required from the FAO side a very active preparatory phase in collaboration with the Near East Regional Commission on Land and Water Use.
- (2) A more active participation in the 1972/73 Programme of the National Committees of the various countries of the Region is badly needed. It is hoped that full-fledged larger scale regional operation on reclamation and management of (i) salt affected waterlogged soils; (ii) calcareous soils; (iii) sandy soils; and (iv) efficient use of irrigation water - will be launched in January 1973, pending final approval of the Regional Project by UNDP.
- (3) The modest start for 1972/73 advised by the FAO Secretariat during the Damascus Seminar (December 1971) was agreed upon by the Regional Commission. Guidelines and experimental layouts, Reclamation and Management of Salt Affected Soils, and Crop Water Requirement Experiments were issued and discussed. It was indicated that time is needed for their study and evaluation on a regional basis.
- (4) Comments and viewpoints of specialists and researchers on the Guidelines and Experimental Layouts in the various countries were requested by the Regional Officers. Responses are given and discussed in this paper. While certain suggestions could easily be integrated in the proposed guidelines and experimental layouts, others would require further elaboration or even new experimental designs. This applies, in particular, to the request of the Arab Republic of Egypt for a compound experiment for interactions of fertilizer levels, salinity levels, water table depths and irrigation regimes. Iraq and Syria could benefit from the additional experimental layouts. Experiments for the use of low quality and brackish water were also requested (Cyprus). Results for immediate use in ongoing land and water development projects were strongly requested by Syrian and other Government officials. The need for improved irrigation methods and good training and extension was expressed to make full use of the crop water experiment data.
- (5) At present, it may be considered that Crop Water Requirement experiments, according to or in line with the Guidelines, are fully operating in Lebanon, well implemented in Jordan, initiated in Cyprus, Iraq, Iran and Syria. The initiation was mainly within operating FAO projects.
- (6) Management experiment implemented already in Iran. Steps towards the implementation of the reclamation of salt affected soils and the management of leached soils are being taken in Egypt, Iraq, Iran, Jordan and Syria. The experimental sites were selected and land preparation was proceeding during the FAO Officers' visit. Lebanon and Cyprus are not interested in the problems of salt affected soils.
- (7) The establishment of a Bibliography on previous and current research results and publications dealing with the four lines of action of the Applied Research Programme is required. Bibliographical research was initiated for crop irrigation requirements.
- (8) The roles of the Regional Commission and National Committees on Land and Water Use are essential for the implementation and success of the Regional Applied Research Programme. It is understood that the actual field implementation is the responsibility of the participating countries.

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IV. COUNTRY REPORTS

IV.1.

AFGHANISTAN

1.1. Introduction

Afghanistan is an interesting country, popularly called the land of mountains or the Switzerland of Asia. It lies between 29 and 38° north and the elevation varies from high mountains (up to 7 620 m) to arid desert plains, with the most general height being 1 200 m above sea level. The climate is cold in winter, hot and dry in the summer. Rainfall is scanty, nowhere more than 381 mm annually with much of the precipitation as winter snow and spring rains.

The total area is 653 000 km² with an estimated population of 17 million, 85 percent of which is classified as rural and 15 percent as urban. It is estimated that about 14 million hectares of land is cultivable, with 2.3 million hectares under wheat irrigation.

Afghanistan's economy is dependent on production and export of crops and livestock products. Principal exports are dried and fresh fruits, nuts Karakul pelts, raw cotton, wool, carpets and rugs.

1.2. Soils of Afghanistan

A detailed soil survey of the country is yet to be completed, however a generalized map of the soils of Afghanistan is presented in Fig. 1.

A study of the Genesis of Afghanistan soils indicate that these are developed predominantly from the influence of climate. Since moisture is low, physical weathering is more pronounced than chemical and soil formation has proceeded rather slowly. Most of the products of weathering are retained within the soil itself.

Calcification is the most dominant soil forming process in dry conditions. In areas of low rainfall there is a tendency to evaporation from the surface and replacement from the water table below. The groundwater which is drawn up often contains large amounts of dissolved calcium bicarbonate and on evaporation the calcium carbonate is deposited within the soil-body resulting in an accumulation of this substance. Leaching of the soluble materials from the surface downwards is minimal because of the absence of percolating water.

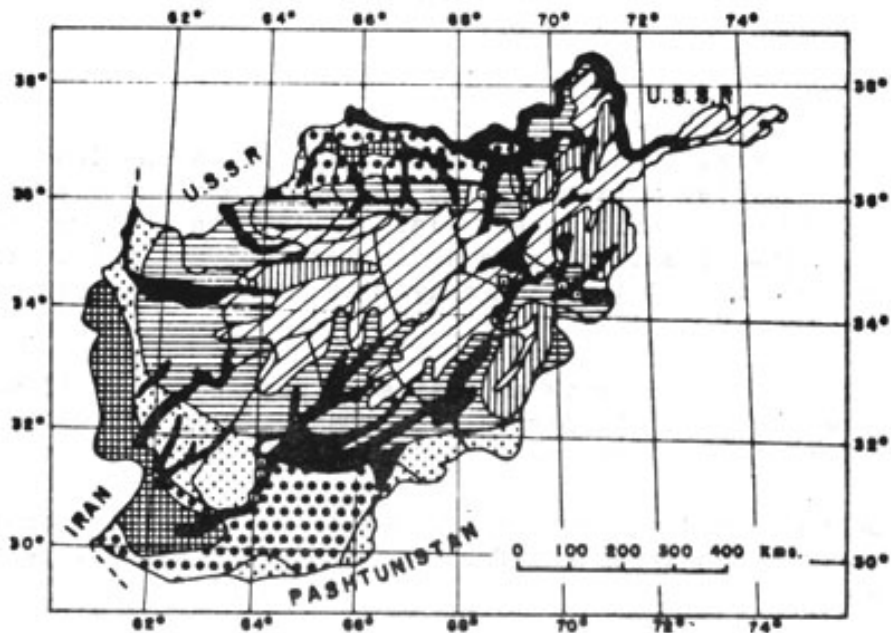
Horizons and features of three representative soil profiles are presented in Fig. 2. An examination of these shows that:

- a) The profile of Kabul silt loam has a marked textural and structural B horizon. In the sub-soil there is an abundance of irregular calcareous nodules, less than 8 cm in diameter. A few calcite tubes, calcareous tubules and columnar Krotovinas, all about 2.5 cm in diameter were observed. A horizontal calcite plate 1 mm thick lay at a depth of 150 cm and was continuous except for the points at which it was pierced by calcite tubes.

FIGURE 1

SOILS OF AFGHANISTAN

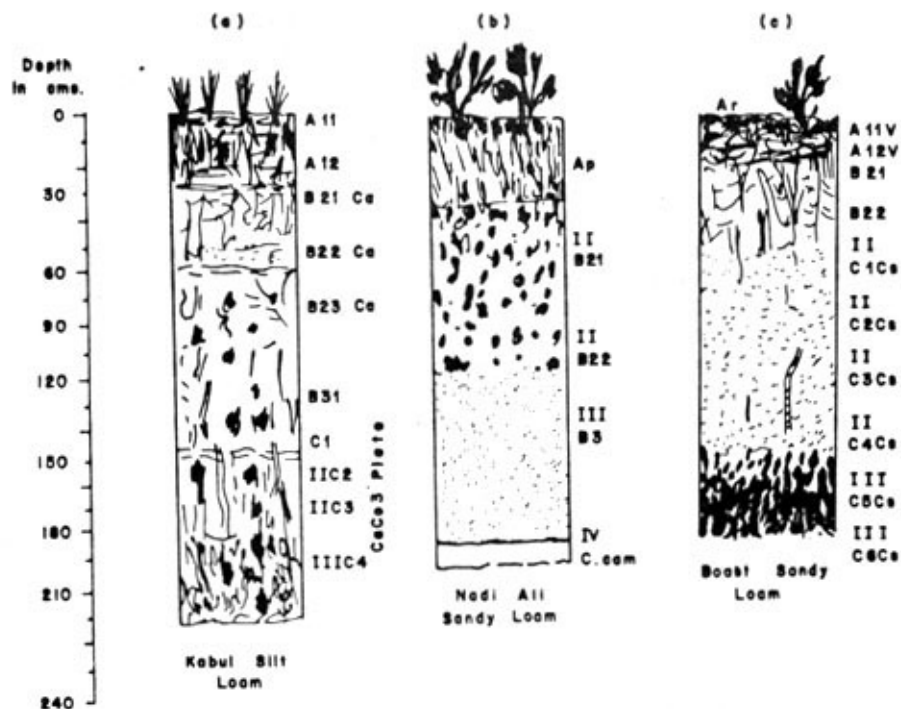
Generalized map, provisional (after Subramanian et al)



LEGEND

- Soil profile site
- ▨ Soils of alluvial plains (Camborthids, Haplargids & Ustifluvents)
- ▩ Saline, Alkali, & salt marsh soils (Salorthids, Natrargids & Haplapuents)
- ▤ Desert soils, mostly dunes (Psammentes etc.)
- ▥ Desert soils, with few dunes (Camborthids, etc.)
- ▧ Sierozem, Brow (Calcorthids & Haplargids) & Mt. soils with Lithosols & Regosols (Orthents)
- ▨ Mountain soils of Chestnut, Padzello & Brown Forest zones, with Lithosols (Haplustolls, Argiustolls, etc.)
- ▩ Mountain soils Forest & Alpine Meadow zones, Glacial ice & Rock Outcrops (Cryaquepts & Lithic groups)

Figure -2- Horizonation and Features of Representative Soil Profiles of Afghanistan



- b) The second profile at Nadi Ali, had a gravelly textural II B horizon under a massive vesicular Ap. Pinkish white calcium carbonate nodules (7.5 yr 6/4 D) less than 1 cm in diameter are abundant in the II B 21. At a depth of 175 cm there is a petro calcic horizon of unknown thickness.
- c) The third profile is undisturbed Boast sandy loam, has a discontinuous desert pavement (Ar), and has the most cemented horizon. The II C1CS between 58 and 82 cm contains more than 50% by volume of calcium carbonate and associated gypsum and salts. The weakly cemented III C6CS horizon does not effervesce with acid.

The soils of Afghanistan are alkaline in reaction. Most of the samples studied have a pH much higher than 7.0. It is estimated that nearly 50% of the soils of Afghanistan have a pH between 8 and 8.5, about 35% between 8.5 and 9.0 and about 10% between 9 and 9.5. It is also known that soils with a pH of 8.0 to 8.5 are generally rich in alkaline earth carbonates, except for the soils of Panjshir Ghorband Valley. All the soils studied so far have a calcium carbonate content of 10% or more; soils of the Ghazani area have in general 10 to 12% calcium carbonate, Kunduz soils show 10 to 15%, Kabul and Katawaz 10 to 20%, Hari-Rud 15 to 20%, and Farah, Logar and Adras Kand areas show 20 to 25% calcium carbonate in the surface samples. Occasionally in some areas CaCO_3 content is more than 40%.

1.3. Response of Wheat, Corn and Sugarbeet grown on the Calcareous Soils of Afghanistan to Fertilization

The excess of calcium carbonate poses serious problems in plant nutrition, mainly because it influences the pH of soil and thus renders micro-nutrients unavailable to plants as well as the unavailability of phosphorus in calcareous soils.

During the FAO Project on soil fertility and fertilizer use, some simple fertilizer experiments were conducted in different provinces of Afghanistan (for details please refer to UNDP/FAO/Report No. TA 30/6).

The average mean yield of wheat as affected by fertilizer treatment is presented in Table 1. Corresponding yields for corn are given in Table 2 and for sugarbeet in Table 3. The average CaCO_3 is given for each province.

From these data it seems that, inspite of high CaCO_3 content, the response to application of N + P is uniformly high and statistically significant. However, more detailed experimentation is needed to draw valid conclusions about management of calcareous soils in Afghanistan.

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Table 1. Mean average yield of wheat as affected by fertilizer treatments (kg/ha)

| Province | Lagman | | Nangarhar | | Kabul | | Logar | | Maidan | |
|---------------------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|-----------|-------|
| Treatment No. | 1969 - 70 | | 1969 - 70 | | 1969 - 70 | | 1969 - 70 | | 1969 - 70 | |
| 1. | 1 167 | 1 719 | 1 087 | 1 835 | 1 655 | 2 012 | 1 378 | 1 691 | 1 089 | 1 628 |
| 2. | 1 542 | 2 167 | 1 406 | 2 251 | 1 814 | 2 647 | 1 555 | 2 363 | 1 290 | 2 346 |
| 3. | 1 800 | 2 339 | 1 710 | 3 205 | 2 031 | 2 768 | 1 727 | 2 482 | 1 441 | 2 408 |
| 4. | 1 427 | 1 953 | 1 310 | 2 288 | 1 985 | 2 383 | 1 637 | 2 087 | 1 367 | 1 658 |
| 5. | 1 540 | 1 806 | 1 398 | 3 094 | 2 148 | 2 379 | 1 721 | 1 982 | 1 469 | 1 991 |
| 6. | 2 281 | 3 710 | 2 265 | 3 864 | 3 133 | 3 925 | 2 539 | 3 157 | 2 776 | 3 327 |
| 7. | 2 052 | 3 273 | 1 954 | 2 704 | 2 590 | 3 327 | 2 024 | 2 787 | 2 418 | 2 671 |
| 8. | 2 292 | 3 039 | 2 340 | 2 871 | 2 596 | 3 478 | 2 168 | 2 790 | 2 428 | 2 913 |
| 9. | 3 197 | 4 522 | 3 304 | 4 382 | 5 420 | 4 781 | 4 769 | 3 909 | 4 900 | 3 980 |
| 10. | 1 704 | 1 826 | 1 321 | 2 038 | 2 134 | 2 211 | 1 684 | 1 860 | 1 407 | 1 946 |
| 11. | 2 354 | 3 814 | 2 319 | 4 026 | 3 158 | 4 018 | 2 591 | 3 322 | 2 487 | 3 379 |
| 12. | 3 310 | 4 650 | 3 376 | 4 533 | 5 573 | 4 764 | 4 618 | 3 885 | 4 690 | 4 056 |
| CaCO ₃ % | 3.0 | | 10.0 | | 14 | | 18 | | 11 | |

| Province | Parwan | | Kapisa | | Ghazni | Baghlan | Kunar |
|---------------------|-----------|-------|-----------|-------|--------|---------|-------|
| Treatment No. | 1969 - 70 | | 1969 - 70 | | 1970 | 1970 | 1970 |
| 1. | 1 296 | 1 681 | 1 296 | 1 748 | 1 461 | 1 946 | 1 641 |
| 2. | 1 574 | 2 202 | 1 574 | 2 400 | 1 997 | 2 350 | 2 485 |
| 3. | 1 738 | 2 603 | 1 738 | 2 733 | 2 311 | 2 579 | 2 700 |
| 4. | 1 570 | 1 963 | 1 570 | 2 156 | 1 894 | 2 225 | 1 833 |
| 5. | 1 589 | 2 411 | 1 589 | 2 620 | 1 889 | 2 203 | 2 770 |
| 6. | 2 499 | 3 643 | 2 499 | 3 615 | 2 781 | 3 791 | 3 876 |
| 7. | 2 335 | 3 013 | 2 335 | 2 845 | 2 605 | 3 159 | 2 915 |
| 8. | 2 332 | 3 127 | 2 332 | 3 136 | 2 233 | 3 000 | 3 491 |
| 9. | 4 180 | 4 418 | 4 180 | 4 015 | 3 444 | 4 302 | 4 208 |
| 10. | 2 029 | 1 943 | 2 029 | 2 551 | 2 066 | 2 280 | 2 100 |
| 11. | 2 711 | 3 777 | 2 711 | 4 281 | 2 761 | 3 289 | 3 610 |
| 12. | 3 968 | 4 486 | 3 968 | 4 603 | 3 411 | 4 333 | 4 441 |
| CaCO ₃ % | 3 | | | | 15 | 17 | 3 |

Treatment

N - P₂O₅ - K₂O

| | | | | | |
|-----|-----|---|-----|---|-----|
| 1. | 0 | - | 0 | - | 0 |
| 2. | 75 | - | 0 | - | 0 |
| 3. | 150 | - | 0 | - | 0 |
| 4. | 0 | - | 75 | - | 0 |
| 5. | 0 | - | 150 | - | 0 |
| 6. | 75 | - | 75 | - | 0 |
| 7. | 75 | - | 150 | - | 0 |
| 8. | 150 | - | 75 | - | 0 |
| 9. | 150 | - | 150 | - | 0 |
| 10. | 0 | - | 75 | - | 100 |
| 11. | 75 | - | 75 | - | 100 |
| 12. | 150 | - | 150 | - | 100 |

Table 2. Mean average yield of corn as affected by fertilizer treatment

| <u>Treatment</u> <u>No.</u> | <u>Fertilizers - kg/ha</u> | | | <u>Yield in kg/ha</u> | |
|--------------------------------|----------------------------|-------------------------------|------------------|-----------------------|---------------------|
| | N | P ₂ O ₅ | K ₂ O | Paktya ^{1/} | Logar ^{2/} |
| 1. | 0 | 0 | 0 | 1 967 | 1 905 |
| 2. | 75 | 0 | 0 | 2 351 | 2 457 |
| 3. | 150 | 0 | 0 | 3 859 | 3 900 |
| 4. | 0 | 75 | 0 | 2 372 | 2 495 |
| 5. | 0 | 150 | 0 | 2 499 | 2 676 |
| 6. | 75 | 75 | 0 | 5 906 | 6 011 |
| 7. | 75 | 150 | 0 | 3 973 | 4 035 |
| 8. | 150 | 75 | 0 | 3 929 | 4 152 |
| 9. | 150 | 150 | 0 | 6 844 | 6 995 |
| 10. | 0 | 75 | 50 | 2 523 | 6 680 |
| 11. | 75 | 75 | 50 | 5 988 | 6 087 |
| 12. | 150 | 150 | 50 | 6 950 | 7 081 |

1/ Soils with 15% CaCO₃

2/ Soils with 18% CaCO₃

Table 3. Mean average yield of sugarbeet as affected by fertilizer treatment ^{1/}

| <u>Treatment</u> <u>No.</u> | <u>Fertilizers - kg/ha</u> | | | <u>Average yield kg/ha</u> |
|--------------------------------|----------------------------|-------------------------------|------------------|----------------------------|
| | N | P ₂ O ₅ | K ₂ O | |
| 1. | 0 | 0 | 0 | 22 666 |
| 2. | 60 | 0 | 0 | 35 333 |
| 3. | 120 | 0 | 0 | 38 666 |
| 4. | 0 | 60 | 0 | 24 145 |
| 5. | 0 | 120 | 0 | 25 594 |
| 6. | 60 | 60 | 0 | 51 536 |
| 7. | 60 | 120 | 0 | 51 471 |
| 8. | 120 | 60 | 0 | 63 600 |
| 9. | 120 | 120 | 0 | 70 637 |
| 10. | 0 | 60 | 60 | 40 785 |
| 11. | 60 | 60 | 60 | 58 346 |
| 12. | 120 | 120 | 60 | 72 633 |

1/ Soils with 17% CaCO₃

2.1. Physical, Morphological and Geological features of Cyprus

Cyprus is an island in the eastern Mediterranean sea lying between $34^{\circ}33'$ to $35^{\circ}41'$ North and between $32^{\circ}20'$ to $34^{\circ}35'$ East, 70 km from southern Turkey, 100 km west of Syria and 370 km north of Egypt.

Its maximum length is 225 km east to west and its greatest width is 96 km north to south. It covers an area of 9 250 km² of which some 47 percent is arable and about 25 percent under forests. Out of a total population of 640 000, 35 percent of the economically active population is presently engaged in agriculture.

The island is transversed by two mountain ranges, the high Troodos massif in the southwest with the highest peak, Olympus, at 2 000 m and the long narrow Kyrenia range rising to 900 m and bordering the northern coast. Between the two mountain systems lies the central plain, and along their seaward margins a more or less narrow coastal strip.

The Troodos massif consists of igneous rocks, while the Kyrenia range is hard crystalline limestone. Over almost half the central plain there are middle miocene and post middle miocene calcareous marine sediments, such as marls and limestone outcrops. The rest of the plain is covered by pleistocene calcareous or non-calcareous deposits, and by recent calcareous alluvium in some low lying areas. The coastal strips consist of upper miocene to upper pliocene limestones and marls in places, while the rest is covered by pleistocene calcareous or non-calcareous deposits and by recent calcareous alluvium.

Middle miocene soft bedded limestones and chalks stretch from east to west of the southern part of the island over a distance of approximately 145 km. This stretch of land, frequently dissected by deep, narrow valleys, cut down by young rivers flowing to the sea, constitutes the southern flanks of the Troodos massif, and due to favourable climatic conditions, extensive vine plantations have been established on these extremely calcareous soils.

2.2. Climate

The climate of Cyprus has the characteristic features of the arid Mediterranean basin, with a cool wet winter followed by a hot and practically rainless summer. Cyprus, at the northeast corner of the Mediterranean sea and 3 200 km from the Atlantic ocean, is surrounded by much larger land masses and furthermore, these lands around Cyprus are of a dominant arid and semi-arid character. On account of its position Cyprus is influenced by modified continental air masses. Many travelling lows, however, are diverted at the southern corner of Turkey and leave Cyprus unaffected. In addition the major winter front, originating from the Icelandic low and covering most of Europe, seems to end in southern Turkey.

2.2.1 Precipitation and its distribution

Most of the rain falls between November and April, 50 percent of it in December and January. The average annual precipitation ranges according to elevation from 320 mm in

the central plain and 500 mm in coastal areas to 800 mm at highest elevations. However, in dry years the central plains receive less than 200 mm of annual rainfall.

Winter rain is the most important element to the vegetative environment of the island as, in addition to the replenishment of the groundwater resources, it provides for the evapotranspiration requirements of dryland farming (cereals, carobs, olives and vines). Its distribution even in the rainy months is uneven and low precipitation in March-April affects adversely the performance of rainfed cereals during their critical physiological stage.

2.2.2 Temperature

The monthly mean maximum temperature in the central plain ranges from 15°C in January to about 35°C in July and August. The coolest areas are the most elevated, Olympus (2 000 m) having a mean maximum of 26°C in August.

The mean minimum temperature ranges from about 5°C to 20°C and frost, although infrequent, may happen unexpectedly.

2.2.3 Relative humidity

The average monthly relative humidity ranges from 40 to 80 percent in the inland plain with lowest in the summer, 50 to 85 percent in the coastal areas and 40 percent in the summer and 80 percent in January-February on the Troodos massif.

2.2.4 Evaporation and evapotranspiration

Evaporation (E pan) in the central plain and measured by USWB class 'A' pan reaches an annual total of 1 750 mm. In coastal areas annual cumulative pan evaporation is somewhat lower at around 1 500 mm. Evapotranspiration (ETp) calculated by Penman formula is about 70 percent of pan evaporation. Typical data obtained for Nicosia were as follows:

| J | F | M | A | M | J | J | A | S | O | N | D | Year |
|----|----|----|-----|-----|-----|-----|-----|-----|-----|----|----|---------------|
| 37 | 45 | 85 | 143 | 206 | 269 | 285 | 260 | 196 | 119 | 61 | 39 | 1 745 mm Epan |
| 31 | 41 | 68 | 108 | 142 | 181 | 192 | 184 | 130 | 87 | 46 | 28 | 1 238 mm ETp |

2.3. Soils

From the pedogenic point of view the soils of Cyprus bear the strong impact of the aridity of the climate and the diversity of the topography, both of which seem to have acted dominantly on the parent material and to have subjugated to secondary importance the contribution of vegetation in the processes of soil formation.

The shallowness of the soil profile and the almost complete lack of well-defined diagnostic horizons indicate that the large soil moisture deficit created from low precipitation and high evapotranspiration has arrested the speed of the soil forming processes known to be active under more humid climates.

Essentially then the soils of Cyprus are typified by this Mediterranean character resulting in low organic matter, high calcium carbonate content in surface horizons, high pH, low mineral nitrogen, low phosphorus and high total and exchangeable potassium.

2.3.1 Soil surveys

Soil survey forms an important part of the activities of the Department of Agriculture under the Ministry of Agriculture and Natural Resources. A systematic soil survey designed to cover the whole island has been in progress since 1956. Until the present, over 300 000 hectares or 70 percent of the cultivated area of the island have been surveyed and covered by detailed soil maps.

In some watersheds land suitability surveys were carried out concurrently with detailed soil surveys in conjunction with proposed development projects, to propose the best land use based on soil properties, climate and availability of irrigation water.

2.3.2 Soil classification

Until 1970 the agricultural soils of Cyprus were classified as:

- Rendzinas - light-coloured calcareous soils formed on soft highly calcareous rock or calcareous colluvium and alluvium;
- Terra Rossa - red-coloured fine-textured soils on hard calcareous crust overlying soft mass of limestone;
- Alluvial soils- formed on recent water-borne deposits extensive in the central plain
- Carbonate raw - formed on calcareous parent material;
soils
- Silicate raw - formed on igneous materials;
soils
- Brown earths - formed on basic volcanic and plutonic rocks;
- Red soils - formed on igneous conglomerates.
(rotlehm)

In 1970 the new system of soil classification introduced by the European Commission on Agriculture of the U.N. was adopted and a general soil map of the island at a scale 1:200 000 has been prepared. Under this system the soils of Cyprus fall into nine orders, namely, Lithosols, Solonchaks, Vertisols, Xerosols, Solonetz, Cambisols, Rendzinas, Luvisols and Rhagosol.

The distribution of most of the Cyprus soils classified according to the above-mentioned orders and sub-orders is approximately as follows:

| <u>Order</u> | <u>Sub-order</u> | <u>Area, km²</u> |
|--------------|-------------------------|-----------------------------|
| Lithosol | calcaric | 2 280 |
| | eutric (igneous, lavas) | 137 |
| Solonetz | orthic | 283 |
| Solonchaks | gleic | |
| Xerosols | haplic | 770 |
| Lithosols | calcaric | |
| Vertisols | chromic (mamonia) | 103 |

| <u>Order</u> | <u>Sub-order</u> | <u>Area, km²</u> |
|--------------|--|-----------------------------|
| Vertisol | calcaro pellic) | 269 |
| Lithosols | calcaric } central plain alluvials of low EC | |
| Cambisols | vertic | 291 |
| Cambisols | calcaro chromic (reddish brown) | 1 142 |
| Cambisols | eutric (igneous) | 1 434 |
| Rendzinas | orthic } | 832 |
| Lithosol | calcaric } limestones | |
| Rhegosols | calcaric | 269 |
| Rhegosols | calcaric } | 229 |
| Vertisols | verlic } alluvial | |
| Luvisols | rhodo chromic } | 317 |
| | rhodo calcic } | |

2.3.3 Calcareous soils and their distribution

Soils in Cyprus are calcareous with the exception of those developed on hard igneous rocks of the Troodos massif, on non-calcareous swelling clays outcropping to the southwest and on some pleistocene non-calcareous deposits of the central plain and the coastal strip which could be termed as non-calcareous. It is worth noting here that the vast majority of soils in Cyprus contain free calcium carbonate, they have a predominantly Ca-saturated clay and their pH determined in a 1:5 soil to water suspension is above 7.5.

Soils referred to as "calcareous" vary in lime content from those having a small concentration somewhere in the profile to those containing an appreciable amount of lime throughout the profile. The term "calcareous soils" is used here to designate soils in which the lime content is sufficiently high to affect adversely the nutrition of crops, reduce productivity of the soil and narrow the choice of crops that could be grown on such soils.

The following calcium carbonate classes if adopted could be used for separating calcareous soils associated with properties that may adversely affect plant nutrition, from the rest of calcareous soils:

| <u>Calcium Carbonate Classes</u> | <u>CaCO₃ Content</u> <u>%</u> |
|--|---|
| (1) Non or almost non-calcareous soils | < 5 |
| (2) Slightly calcareous soils | 5-15 |
| (3) Moderately calcareous soils | 15-35 |
| (4) Calcareous soils | 35-55 |
| (5) Very calcareous soils | 55-75 |
| (6) Extremely calcareous soils | > 75 |

The distribution of Cyprus soils according to the above system of classification and the proposed calcium carbonate classes may be summarized as follows:

soils developed on the Troodos massif are practically non-calcareous Eutric Cambisols and Eutric Rhegosols;

soils developed on the Kyrenia range are on the majority calcareous and have been classified as Calcaric Lithosols and Mollic Rendzinas;

over the central plain the soils occurring extensively are classified as Calcaric Lithosols and Orthic Rendzinas which are very calcareous; Xeric Vertisols, Calcaric Cambisols and Calcaric Rhegosols which are calcareous; and Rhodic Vertisols, Pellic Vertisols and Vertic Cambisols which are moderately calcareous;

in the northern coastal strip the soils are Pellic Vertisols which are moderately calcareous and Calcaric Cambisols which are calcareous;

soils on the southern coastal strip are Calcaric Cambisols and Calcaric Rhegosols which are calcareous; Chromic Vertisols and Pellic Vertisols which are moderately calcareous; and Gleyic Solonchaks which are very calcareous;

soils developed on the marls, limestones and chalks on the southern flanks of the Troodos massif are Calcaric Lithosols and Ochric Rendzinas which are very or extremely calcareous.

2.3.4 Clay Mineralogy

Preliminary results obtained recently from X-ray defraction analysis of clay minerals from a limited number of soils indicate that throughout a 120 cm profile of an alluvial Calcaric Rhegosol, 2:1 lattice minerals predominate with abundant montmorillonite and beidellite and some illite. The predominant minerals in two Rhodo Chromic Luvisols were illite and Kaolinite with some montmorrillonite.

2.3.5 Soil fertility and nutrient availability

As mentioned earlier the agricultural soils of Cyprus in their natural state are poor in nitrogen (0.1 %), poor in organic matter (around 1 %), poor in available phosphorus and rich in total and exchangeable potassium.

Although magnesium is generally in good supply, especially in soils developed on igneous rocks, it may be short in some others.

Lime-induced chlorosis is observed under conditions of high calcium carbonate content coupled with high moisture regimes and on calcareous soils where the surface horizon has been removed in the process of land levelling.

Zinc deficiency is by far the most prevalent micro-nutrient disorder especially in tree crops such as citrus and deciduous.

From leaf analyses manganese seems to be in short supply for some crops but this may not at present be of economic importance.

In spite of the adequate supply of soil potassium, application of potassic fertilizers does not improve the uptake of this element by irrigated tree crops, presumably because of excessive Ca^{++} in the soil solution and possibly due to fixation by clay minerals.

2.3.6 Fertilizer consumption

Whereas in 1960 agriculture in Cyprus used 6 500 t of N, 7 500 t P_2O_5 and 500 t of K_2O , in recent years fertilizer consumption rose to 13 500 t N, 10 000 t P_2O_5 and

1 900 t of K_2O . Thus the value of all fertilizer imports is over £2 million a year. It is estimated that more than 50% of the fertilizer import is consumed by irrigated crops, such as citrus, potatoes and other vegetables representing only 12% of the total cultivated area.

2.3.7 Crop responses

Crops in general respond to fertilizer nitrogen applications and to a lesser extent to phosphorus. Responses of crops to soil application of potassium are an exception rather than the general rule.

Soil fertility studies were the first agricultural research activity embarked upon, long before the establishment of the Agricultural Research Institute in 1962. Since then experimental work in soil fertility has been expanded considerably to include fertilizer field experiments and plant nutrition studies of the most important irrigated and rainfed crops such as citrus, potatoes, carrots, vines, wheat and barley.

From the results of long term experiments the responses of individual crops is summarized in the following paragraphs.

a) Fertilizer Use by Major Crops

Potatoes: previous and recent experiments on fertilizer requirements by potatoes of the commonly cultivated varieties, Arran Banner and Up-to-Date, have established that high yields are attainable with only 110 kg of N applied as sulphate of ammonia and 90 kg P_2O_5 as single superphosphate per hectare per year all applied at planting. This has been re-established from recent work on the fertilization of potatoes in the main growing areas of Terra Rossa. In these experiments close planting at 18-20 cm in rows corresponding to 70 000 plants per hectare irrigated by sprinkling could produce up to 50 tons of Arran Banner and 45 tons of Up-to-Date. Doses of nitrogen above 150 kg of N per hectare always tended to decrease production. Phosphorus on the other hand, even used at higher rates, had no ill-effect on production. Most of the fields sampled in a survey showed that they had acquired high levels of available phosphorus by the continuous use of high rates of phosphatic fertilizers. Potassium, on the other hand, has never increased yields or improved the quality of potatoes. These findings come in sharp contrast to the practice of potato growers who firmly insist on fertilizing with high doses and up to 2.8 tons/ha of the mixed types of fertilizer 14-22-0 or 14-22-9. On the basis of the present area cultivated with potatoes, it is estimated that the potato growers could save up to £250 000 per year if they were to adopt the recommended fertilizer rates.

Carrots: experiments on the fertilization of carrots grown on Rhodo Chromic Luvisols developed on igneous pebbles have shown that very high exportable yields of 75-80 tons/ha of the variety Chantenay could be achieved when fertilized with only 110 kg N/ha as sulphate of ammonia and 90 kg P_2O_5 /ha as single superphosphate, all applied at planting. Mechanical triple-row planting and sprinkler irrigation have been used and the high yields are not only attributed to the right combination and amount of fertilizers used but also to the mechanical triple-row planting and the sprinkler irrigation for maintaining high moisture regimes.

Citrus: within the objectives of the Agricultural Research Institute's crop programme, the study of all aspects of citrus production is of paramount importance. Nutrition and fertilizer requirements of citrus are major aspects of citrus management. Two experiments on the fertilization of Valencia oranges at Morphou (Calcaric Rhegosols) were established in 1962. The results of these experiments so far indicate that 14-year old Valencia orange trees

require up to 0.75 kg N/tree as sulphate of ammonia applied in February and 0.25 kg N/tree as nitrate applied in early July to supplement the nitrogen requirements of Valencia growing in light textured soils. The phosphorus requirement under the same conditions was found to be 0.2 kg P₂O₅/tree triple superphosphate per year. Potassium, on the other hand, has not been found to affect either yields or quality of the fruit inspite of the fact that the potassium leaf levels have dropped from 1.15 - 0.65 % since 1962. However, the present levels of potassium in the leaves are considered "low" and current studies are directed towards finding ways and means to increase potassium content in the leaves. In connection with the serious problem of the creasing of Valencia oranges in the Morphou area, which causes serious losses in certain years, a number of experiments have been set up with a view to finding the cause and a remedy for this symptom.

Apples: production is important in certain regions of the island where the climate is sufficiently cold to allow the cultivation of this crop. In addition, the expansion of apple culture makes it necessary to carry out experimental work to determine the fertilizer requirements. An experiment was initiated in 1962 on a Rendzina where the nitrogen, phosphorus and potassium requirements of apples are being studied. So far, although no conclusive results can be cited, it is indicative that apples require 1 kg Nitrogen, 0.3 kg P₂O₅ phosphorus and, interestingly enough, no potassium. In another small experiment initiated at Saittas on the Lord Lambourne variety of apples, it has been shown from leaf analysis at intervals that N, P and K are continuously on the decline from the beginning of July until harvest of the apples.

Lucerne: This has been used as a test crop in a long-term field experiment at Morphou whereby the interest was to find out the direct and residual effects of phosphate fertilization and at the same time exhaust the phosphorus and the potassium of the soil. So far, it has been found that lucerne will require up to 200 kg P₂O₅/ha/year in order to maintain high production of up to 120 tons of green matter/ha/year. This is equivalent to about 24 tons of dry matter containing roughly about 5 tons of crude protein. In rotation with lucerne, potatoes have been grown and it was found that they too responded to direct application and to residual phosphorus in the soil.

Application of increasing rates of potassium to lucerne resulted in the reduction of the magnesium content. Similarly zinc was reduced from 30 ppm to 20 ppm with the application of 200 kg P₂O₅/ha.

b) Dryland Crops

Olives: a long-term experiment on olives in a Calcaro Chromic Cambisol was carried out in Kyrenia in which the nitrogen, phosphorus and manure requirements of olives was studied. The results over the years have shown that the best combination under trial conditions for maximum olive production was 0.75 kg N as sulphate of ammonia and 0.2 kg P₂O₅ of single superphosphate per tree per year applied in early February.

Carobs: the results obtained from a long-term experiment carried out at Paphos, have shown that fertilization with 0.75 kg N as sulphate of ammonia and 0.2 kg P₂O₅ as single superphosphate per tree per year increased yields on the average by about 30%, in addition to the increase of N and P in the leaves.

Wheat: in a recent four-year cycle of experiments on wheat fertilization in the main wheat belt of Mesaoria (Calcareo Pellic Vertisols) the nitrogen and phosphorus requirement of both Kyperounda (durum) and Pitic 62 (soft) were studied. It was found that under most conditions Pitic outyielded Kyperounda by 40 percent and that it also responded to higher rates of nitrogen fertilization. On the other hand, Kyperounda responded very markedly to the application of nitrogen as indicated by higher levels of nitrogen in the grain.

In a parallel experiment in 1968/69 on the effect of nitrogen fertilization and of supplementary irrigation at critical stages of the growth of three wheat varieties: Kyperounda, Pitic 62 and 8156, it was again verified that Pitic was superior in grain yield compared to the other two varieties. Generally, nitrogen fertilization increased yields but at the same time high rates of nitrogen were found to induce lodging of Kyperounda. On closer examination of the statistical interaction of varieties and nitrogen levels, it became clear that Pitic continued to respond at the higher levels of nitrogen applied. The corresponding yield of grain in tons/ha for 1969 at Athalassa were as follows:

| <u>Kg N/ha</u> | <u>Pitic 62</u> | <u>8156</u> | <u>Kyperounda</u> |
|--------------------|-----------------|-------------|-------------------|
| N ₀ 0 | 3.05 | 2.70 | 2.28 |
| N ₁ 30 | 4.10 | 3.56 | 3.08 |
| N ₂ 60 | 4.45 | 3.62 | 3.30 |
| N ₃ 90 | 4.73 | 3.49 | 3.23 |
| N ₄ 120 | 4.69 | 3.53 | 3.19 |

With respect to supplementary irrigation no striking differences were obtained because of the high rainfall in the winter of 1968/69.

Vines: from long-term NPK experiments with rainfed vines growing on Orthic Rendzinas it has been established so far that vines respond to nitrogen application up to 150 kg N/ha as sulphate of ammonia producing on the average 7 tons of fresh grapes per hectare. However, there has been some indication that significant losses of nitrogen as ammonia may occur from application of ammonium sulphate.

Response to phosphorus application has been observed in one location (available soil P 12 ppm, Olsen 25°C).

No responses have so far been observed from potassium applications.

In a sultana table grape experiment on a Chromic Vertisols irrigated once in early May there were marked linear responses to nitrogen up to 200 kg N/ha applied as sulphate of ammonia (N₀ 10 tons fresh grapes/ha, N₃ 15 tons fresh grapes/ha).

No phosphorus or potassium responses were obtained so far.

2.3.8 Nutrient status

In order to complement and to evaluate meaningfully the results obtained in field fertilizer experiments extensive and detailed analytical work is carried out on soil and plant material.

Concurrently nutrient status surveys, especially of high cash tree crops such as citrus and deciduous, are undertaken from time to time in order to establish the effect of current fertilizer practices on yield and quality and to compare the results of these surveys with the norms of macro- and micronutrients obtained from long-term experiments.

In the case of Valencia oranges we have established that the norms for N, P and K, Zn, B, Mn and Cu in six-to-seven month old leaves from non-bearing growth suggested by Californian workers are, in the main, applicable to Cyprus conditions as well.

From nutrient status surveys we have also found that in citrus high leaf nitrogen levels were prevalent as a consequence of excessive amounts of nitrogenous fertilizers used by the growers which had resulted in the deterioration of fruit quality.

2.4. Water Resources

The Government of Cyprus, recognizing the urgent need to implement an overall water policy and a masterplan for the utilization and development of the island's scarce water resources, received UNDP assistance in instituting the Cyprus Water Planning Project with the main object to take an inventory of the island's water resources and to identify viable development projects. The conclusions of this survey were:

- (a) the total available water was estimated around $960 \times 10^6 \text{ m}^3$ per year of which some $400 \times 10^6 \text{ m}^3$ are being used at present for various purposes.
- (b) even when full development of the water resources has taken place by the end of this century, it is estimated that water utilization will be around $600 \times 10^6 \text{ m}^3$ per annum or about 60 percent of the potential water, and
- (c) the additional water available to agriculture will be insignificant.

The most notable feature of the last decade has been the increase and diversification of crops in irrigated areas and the contribution made by irrigated crops to the total value of the agricultural output. Of the total area cropped irrigated crops occupy some 43 000 hectares or 13 percent of the total cultivated area. Of these, citrus occupy some 14 000 ha and vegetables, including potatoes, another 15 000 ha. Dryland crops occupy 281 000 ha of which 141 000 ha are cultivated with cereals.

Thus future projections for increasing the irrigable land do not seem promising. However, in view of the importance of irrigated agriculture, which contributes over 55 percent of the value of agricultural production, the urgency for the most economic and efficient use of the presently available water resources is pressing.

2.4.1 Water use research

Given this state of realities, apart from the various measures taken by Government for promoting the most efficient use and conservation of the available water resources, water use field studies have commended a high priority in the overall programme of the Agricultural Research Institute since its establishment. A major part of the activities in the soils and water use field is devoted to the determination of the water requirements of irrigated crops such as citrus, potatoes, vegetables and table grapes, including comparison and evaluation of methods of irrigation. In parallel, microclimatological data are collected for calculating evapotranspiration for comparison with values determined in the field.

Salinity studies are undertaken in conjunction with each irrigation field study with the object of supplementing crop water requirements with those of leaching. The results obtained so far from this work are summarized below.

2.4.2 Water requirements of crops

Citrus

In a long-term irrigation experiment on Valencia oranges at Morphou it was established that this crop required 6 000 - 7 500 m³/hectare of water during the period of April to October. This corresponded to 0.50 - 0.65 of pan evaporation (USWB Class A) amounting to about 1 500 mm annually (ETp = 1 250 mm).

Even with good quality irrigation water (EC - 1 mmho/cm) and inherently good drainage, salinity tended to build up within the root zone when low amounts of water were applied which did not permit leaching.

The experiment has now been modified to allow a wider range of amounts of water to be applied in order to determine the additional field leaching requirements.

Potatoes

In a three-year cycle of irrigation experiments on Terra Rossa it was established that this crop responded favourably to frequent irrigation but that excessive amounts of water lowered yields. The optimum amount of irrigation water applied varied from season to season but corresponded to about 0.8 of pan evaporation in April and the first-half of May. Thus the supplementary irrigation for this period for maximum yields amounted to around 1 500 m³/ha. Rainfall contributed to moisture storage prior to the commencement of the irrigation season.

Table Grapes

In an experiment initiated in the spring of 1972 the response of sultana grapes to different amounts of water applied and the comparison of the sprinkler method of irrigation with the border method were studied. Although there had been no significant difference between the two methods of irrigation, significant responses were obtained from different amounts of water applied. The mean effects on yields of fresh grapes are shown in the following Table:

| Method of Irrigation | Water applied m ³ /ha. | | | | Mean method ± 0.86 |
|-----------------------|-----------------------------------|-------|-------|-------|-----------------------|
| | 0 | 1500 | 2400 | 3800 | |
| | | | | | |
| | | | | | |
| Sprinkler | 9.50 | 9.77 | 12.92 | 13.13 | 11.33 |
| Border | 7.72 | 10.54 | 12.91 | 12.79 | 10.99 |
| Mean amount ± 0.86 | 8.61 | 10.16 | 12.92 | 12.96 | |

From soil moisture measurements with a neutron probe it was observed that moisture moved down to 60 cm when irrigated with 1 500 m³/ha and to 90 cm and 120 cm for 2 400 m³/ha and 3 800 m³/ha respectively.

2.4.3 Methods of irrigation

A preliminary study initiated in late 1971 and continued in 1972 aimed at comparing the conventional method of furrow irrigation with the sprinkler and trickle methods.

The test crop used was sweet peppers. The evaluation of these methods, the moisture movement and the salinity profiles as well as the practical and economic problems involved are to be assessed.

2.4.4 Field water balance studies

Two studies initiated in 1972 are continuing with the main objective of evaluating the drainage component in the field water balance equation for a more precise determination of crop water requirements.

Soil moisture changes are followed by neutron probe and tensiometry in order to establish the hydraulic gradient and calculate the hydraulic conductivity of the profile at different depths.

Data obtained so far indicate that the unsaturated hydraulic conductivity varies widely from layer to layer due to textural difference and the sequence of the soil horizons making the evaluation of the drainage component rather difficult. This complicating situation is likely to occur in most irrigated soils of the island.

2.5. Concluding Remarks

The present character of the soils of Cyprus is the result of the strong effect of aridity on the parent material in a slow process of soil formation and horizon development resulting in the omnipresence of calcium carbonate throughout the profile. Aridity is the dominant feature also of lands in the Mediterranean basin.

In general the agricultural soils of Cyprus are poor in nitrogen and phosphorus and rich in potassium.

The high calcium carbonate contents with attendant high pH impose restricting conditions on the uptake of micronutrients especially zinc, iron and manganese.

The fertility of the soil can be easily restored by the application of the main nutrient elements in the form of fertilizers and of foliar sprays of micronutrients.

A basic requirement for the most efficient use of fertilizers and soil nutrients in general is the continuous supply of moisture to the soil. Prolonged moisture deficits created by the semi-arid climatic conditions have to be supplemented by irrigation whenever possible. However, the scarcity of water resources imposes a further restriction in bringing more land under irrigation and at the same time it underlines the necessity for the meticulous use of water and fertilizer in order to increase crop yields, maintain a high quality of agricultural produce and lower production costs.

Thus the necessity for applied research on the fertility of calcareous soils and on the most efficient use of the scarce water resources available is of paramount importance, not only for Cyprus, but for the Region as a whole.

The Government of Cyprus in perpetuating an effective programme in the development and utilization of the island's land and water resources will lend its active support to regional projects under the Near East Regional Applied Research Programme.

3.1. Introduction

Iran, or historic Persia, is situated between 25 and 39.45° N and 44 to 63° E, covering 165 million hectares of lands with wide ranges of:

- Climate: - Humid to Subhumid in the north
- Semi-arid in the north-west and west
 - Arid to hot desertic in the east, south-east and central Iran
- Geology: - Basic Sedimentary rocks, ultra-basic igneous and acid extrusive rocks of the Precambrian era, up to present time sediments
- Vegetation:- Deciduous forests in the north and west
- Shrubs and Scrubs in the north-west and south-west
 - Steppe and salt tolerant bushes in arid and desertic areas
- Physiography or Geomorphologic Land Types:
- High altitude mountains (up to 6 000 m)
 - Hills, piedmont plains, river alluvial plains
 - Saline flood plains and low lands.

Iran is one of the countries with most parts affected by dry or arid conditions which account for the formulation and accumulation of calcareous materials in some soils as well as salt in some others.

3.2. Calcareous Soils in Iran

According to the studies on soils carried out since 1953, it is clear that with the exceptions of the Caspian Zone, where CaCO₃ has been leached from the soil by high rainfall, the central and south-eastern deserts which are affected by salt and a few small areas of non calcareous origins, the soils of the rest of the country are affected by or combined with lime comprising from 10 to 60% of the soil constituents and/or up to 100% of the calcareous stones.

According to "The Soils of Iran" the areas and the association of calcareous soils are as follow:

| <u>Soil Association</u> | <u>Area in 1 000 ha</u> |
|--|-------------------------|
| <u>I - Soils of the plains and valleys</u> | |
| 1 Fine textured alluvial soils (mainly calcareous) | 4 750 |
| 2a Coarse textured alluvial and colluvial soils and Regosols | 4 500 |
| <u>II - Soils of the plateaux</u> | |
| 7 Brown soils | 6 000 |
| 8 Chestnut soils (calcareous horizon below 50 cm) | 1 000 |
| 5-2a Desert soils - Regosols | 8 000 |
| 6.2 Sierozem soils - Regosols | 9 000 |
| 7-15 Brown soils - Lithosols | 2 000 |
| <u>III - Soils of the Caspian Piedmont</u> | |
| 11 Brown forest (mainly calcareous in sub-soil) | 300 |
| <u>IV - Soils of the dissected slopes and mountains</u> | |
| 12 Brown soils - Rendzinas | 400 |
| 13 Calcareous Lithosols, desert and Sierozem | 35 000 |
| 14 Calcareous Lithosols from saliferous, gypsiferous materials | 12 000 |
| 15 Calcareous Lithosols, Brown and Chestnuts | 24 000 |
| Total | 106 950 |

The figures show that around 65% of the soils of the country are calcareous.

3.3. The Management and Land Use

Calcareous soils are productive under semi-arid to subhumid conditions or with irrigation in the following circumstances:

- (i) when water is available and slope and topography of the land are suitable; these soils are used mainly for irrigated, annual crops or fruit trees;
- (ii) when precipitation is sufficient for dry farming (300-600 mm/h) nearly all the slopes and even the tops of the hills in some places are under dry farming (wheat or barley);
- (iii) when the rainfall is 150-300 mm/a, or yearly distribution is not suitable for cropping, or when rainfall is well above 300 mm but there is no suitable topography for cropping, the main land-use is pasture or forest;

- (iv) in the Caspian zone, on cretaceous and jurassic limestones with very shallow to very deep soil cover of rendzina to brown forest soils there are highly productive forests;
- (v) when rainfall is lower than 150 mm/a, and the evaporation is also high, the lime or gypsum is concentrated immediately below the surface and occurs mostly together with salt; these areas are naturally seasonal or occasional grazing lands or waste lands and deserts, with no vegetation;

Very general land use figures for Iran in 1972 were given as follows:

| | <u>million ha</u> |
|-----------------------|-------------------|
| Occasional grazing | 58 |
| Deserts, waste, urban | 43 |
| Marginal grazing | 25 |
| Productive range | 19 |
| Fallow | 12 |
| Dry farming | 4 |
| Irrigated cropping | 3 |
| Forest | 1 |

3.4. Research and Studies

Different organizations in the Ministry of Agriculture and Natural Resources have various activities on the reclamation or management of lands and soils. Within these organizations the Soil Institute plays the major role in research and studies on soils and has many experimental fields throughout the country.

During the past few years the Soil Institute, which consists of various divisions, has carried out the following activities among many others:

- (i) Land Resources Inventories: various land resources of the country and their potentiality or capability for different land uses have been defined. In this respect more than 40 million ha were surveyed and mapped in the last four years by the Land and Soil Evaluation Division.
- (ii) Soil and Land Classification: this activity was started in 1952 and a great deal of work has been done on the classification of lands for irrigation and on the soil classification of Iran.
- (iii) Soil Fertility Research and Soil and Water Management: many studies, combined with experimental field work all over the country, have been carried out on soil fertility, soil and water management and salt leaching in the last 10 years by the Soil and Water Management Division. This same Division has also done plant nutrition studies in relation to CaCO₃ content and iron and zinc deficiencies in calcareous soils.
- (iv) Soil and Water Conservation: soil conservation on a country-wide scale has been done by the Natural Resources Organization and includes such activities as: afforestation of many degraded forests, dune stabilization, plantation of drought resistant plants in desertic areas etc. Conservation of agricultural soils, however, comes under the Division of Soil and Water Conservation and includes such work as the installation of large scale experimental stations in areas of calcareous soils, e.g. Quin (160 km west of Teheran) and on the basic igneous soils of Tickmeh-Dash (500 km north-west of Teheran) and many other stations in the Provinces.

4.1. Introduction

At present the main problem for agricultural development in Iraq is salinity. Other problems, including the presence of between 15 and 35 percent CaCO_3 , are of lesser importance. Recently, studies were started on the effect of CaCO_3 on the physical, chemical and nutritional characteristics of calcareous soils in Iraq. The effect of CaCO_3 on phosphorus fixation and that of leaching and cropping on CaCO_3 content have been studied but more work is needed in order to obtain definite and clear information on the behaviour of these soils.

4.2. Physiographic Regions of Iraq

The physiographic formation of Iraq is composed of five zones, namely: mountain ranges, undulating low hills, desert land, the Jezira and the Mesopotamian Plain.

4.3. Parent Material of Soils

Most of the parent material in the mountain ranges is limestone; in the undulating low hills it is gravels, conglomerate, sandstone or mudstone; in the Jezira gypsum is dominant, while in the desert land it is limestone. The parent material of the alluvial Mesopotamian Plain is formed by sediments of the Tigris and Euphrates rivers and is generally calcareous containing 15 to 35 percent CaCO_3 in the top metre.

4.4. Distribution of Lime in Iraqi Soils

Most Iraqi soils contain from 15 to 35% lime with few having less than 15% or more than 35%. In the plains of the mountain ranges some soils have only 2-7% in the surface but more than 50% in the sub soil. In the low hills, the soils have more than 25% lime content throughout the profile. The Jezira soils generally contain more than 6% CaCO_3 while those of the desert lands have more than 25% in the surface and up to 50% in the sub-surface layers. The calcareous soils of the Mesopotamian Plain contain from 15 to 35% lime mainly as CaCO_3 (90%) and MgCO_3 (10%).

Generally, the soils of the coarse textured levee contain less carbonate than those of the fine textured basins which could be caused by:

- i) better drainability of the levees; consequently leaching of carbonates would be more than in other soils;
- ii) the decrease in size of the lime particles as they move in the water stream before being deposited on the fine textured soils of the basins.

Calcite crystallites are found in all separates of Iraqi soils, but mainly in the silt fraction. They are the main source of calcium ions in the soil solution even though their solubility is low.

4.5. Distribution of Lime in the Soil Profile

The lime distribution is usually homogenous within the soil profile, but in recent sediments the top metre has a higher lime content which increases with depth and with the age of these sediments. In the old soils of northern regions, the lime content also increases with depth.

In the calcareous soils of Iraq, lime can be found in the following forms: fine calcite, calcite intercalary crystals, calcite crystal chambers, calcite crystal tubes, calcite crystal sheets, calcitan lining some pores, neocalcitans deposited around some pores, amorphous deposits as a result of high groundwater levels in southern Iraq, soft lime nodules, Petrocalcic layer and Lithorelics.

The lime in the soil of the Mesopotamian Plain originates from the limestone rocks of the mountain ranges. Due to soil erosion, lime is transported in the rivers' streams as small particles and deposited under the same conditions as the sand, silt and clay soil particles. A few of the results taken from thousands of samples are presented in Table 1 and the following remarks can be made.

- i) There is a difference in the lime content of the sediments transported by the Tigris and Euphrates rivers; the lime content in the former being higher by 2-5%. This characteristic can be used to differentiate between the sediments of the two rivers.
- ii) Coarse textured soil samples contain less lime than those with a fine texture as shown in Table 2. This is due to the effects of turbulence, caused by the velocity of the flowing water on the size of the suspended lime particles and their sedimentation; a decrease in velocity of flow permits the sedimentation of finer particles.

On this basis one can explain the formation of sandy soils with a relatively low lime content in the northern regions and those with a heavier texture and higher lime content in the southern ones. The sedimentation of the lime particle fractions is in harmony with the following physiographic units: river levee, river basin, silted basin and silted basin depression.

Table 1. Average lime content to a depth of one metre in the soils of the various Governates of Iraq

| Governate (Arabic) | No. of samples | Lime content % | |
|-----------------------|-------------------|----------------|---------|
| | | Range | Average |
| Basra | 24 | 27 - 38 | 33 |
| Muthanna | 8 | 23 - 28 | 26 |
| Thi-qar | 4 | 27 - 30 | 28 |
| Waset | 20 | 24 - 35 | 29 |
| Babylon | 41 | 18 - 32 | 27 |
| Baghdad | 45 | 21 - 38 | 28 |
| Anbar | 11 | 18 - 39 | 28 |
| Diala | 10 | 26 - 35 | 31 |
| Kirkouk | 11 | 23 - 36 | 32 |
| Arbiel | 1 | ... | 20 |
| Sulaimaniya | 5 | 12 - 18 | 14 |
| Nineveh | 1 | ... | 6 |

Table 2. Relation between soil texture and lime content in representative samples from two projects

| Project | Light textured profile | | | Heavy textured profile | | |
|------------------|------------------------|-----------|--------|------------------------|----------------|--------|
| | depth cm | texture | lime % | depth cm | texture | lime % |
| Almouthana | 0 - 10 | clay | 29 | 0 - 14 | sandy loam | 14 |
| | 10 - 40 | clay | 28 | 14 - 36 | silt clay loam | 20 |
| | 40 - 70 | clay | 27 | 36 - 66 | sandy loam | 18 |
| | 70 - 95 | clay | 28 | 66 - 96 | sandy loam | 20 |
| | | | | 96 - 120 | loamy sand | 17 |
| Greater Mussayeb | 0 - 12 | clay loam | 29 | 0 - 16 | sandy loam | 20 |
| | 12 - 34 | clay | 30 | 16 - 37 | loamy sand | 19 |
| | 34 - 65 | clay | 32 | 37 - 47 | silt loam | 26 |
| | 65 - 94 | silt clay | 30 | 47 - 74 | sand | 19 |
| | 94 - 129 | silt clay | 27 | 74 - 104 | loam | 24 |
| | | | | 104 - 150 | loamy sand | 19 |

4.6. Effect of Lime on Reclamation of Iraqi Soils

Although 15 to 35% lime is found in most Iraqi soils, as shown in the Map, its presence does not pose a serious problem to land reclamation and development as is the case with a high salt content. Studies have been carried out in various parts of the country on soil reclamation and the following are cited as examples.

- i) Experimental work was started in Dujailah area (Mesopotamian Plain) in 1956. Soils were highly saline with about 6% salts in the top 30 cm, of medium texture, below average permeability (80 cm/day) and with a 20 - 30% lime content. It proved possible to reclaim these soils by leaching and most field crops could be grown thereafter.
- ii) Studies, investigations and reclamation work started in Abu Ghraib (Mesopotamian Plain) in 1969. The soils were highly saline, of heavy texture and contained 25 - 30% lime. Due to the presence of lime and the possibility of leaching excess salts, cropping was successfully achieved afterwards.
- iii) Reclamation experiments in Twairef took place from 1961 to 1969. This area represents the saline soils in the upper basin of the Euphrates river. Salinity was 74 mmhos/cm, the texture varied from sand to light clay and the lime content was about 25%. Results of experiments indicated that the water table could be lowered, salinity decreased and that economic yields from all crops included in the rotation (as shown in Table 3) could be produced. No side effects were observed from the presence of lime in the soils.

Distribution of lime in soils in different physiographic regions of Iraq
(to a depth of one metre)

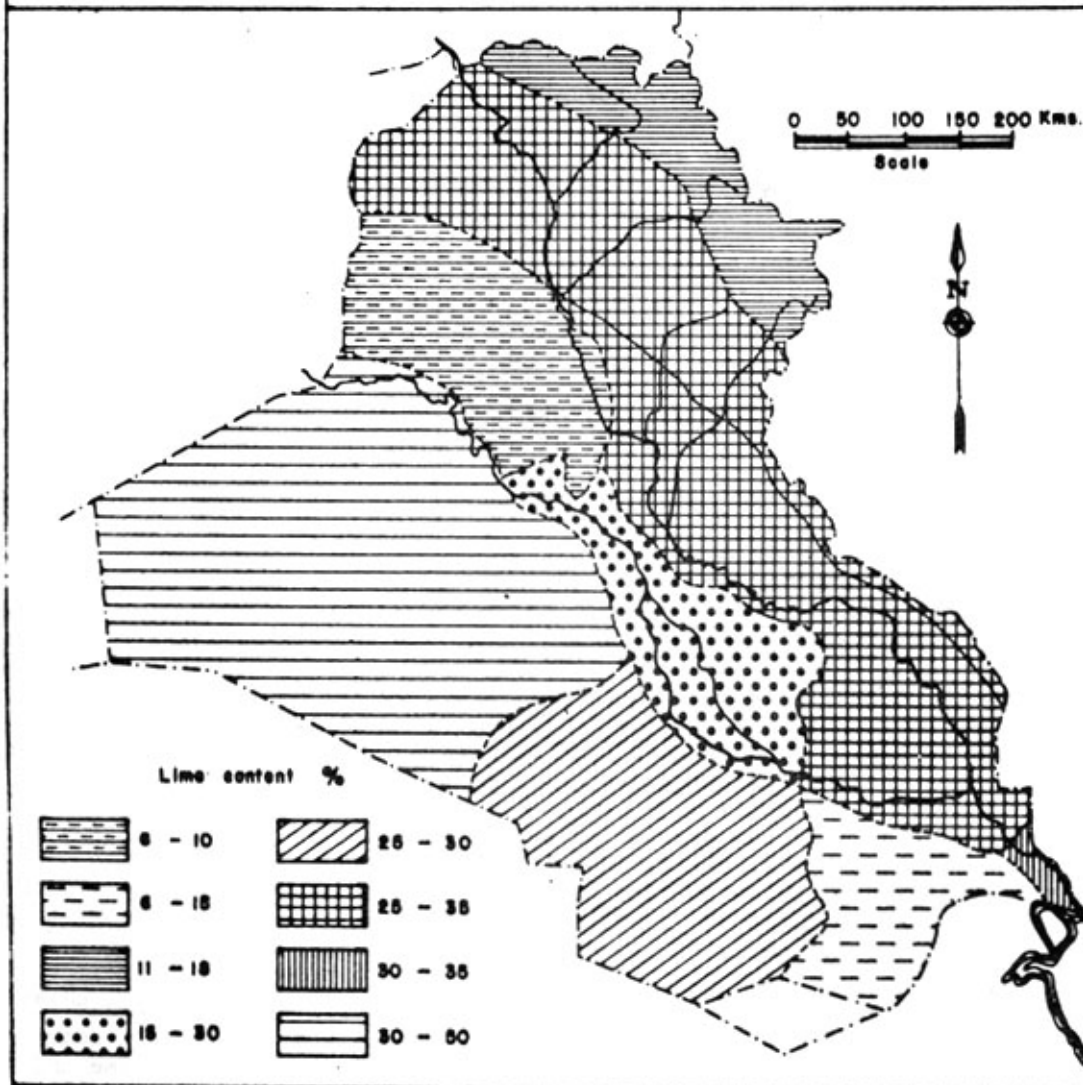


Table 3. Relation between reclamation procedures, wheat year net returns per donum $\frac{1}{}$ during three years

| Reclamation Procedure | Drains | | Average yield of wheat in the last year per donum $\frac{1}{}$ | Salinity | | Net return | |
|---|-----------------|-------|--|----------|-------|------------|------|
| | distance metres | depth | | initial | final | Dinar | Fils |
| 1. Leaching with 80 cm; barley, green gram, barley, green gram, wheat | 100 | 1.8 | 265 | 11 | 0 | 16 | 600 |
| 2. Leaching with 30 cm; wheat, fallow, wheat, fallow, wheat | 100 | 1.8 | 318 | 26 | 0 | 20 | 200 |
| 3. Leaching with 30 cm; wheat | 100 | 1.8 | 385 | 17 | 0 | 21 | 100 |
| 4. No leaching; barley, rice berseem, berseem, wheat | 100 | 1.8 | 421 | 7 | 0 | 13 | 800 |
| 5. No leaching; barley, fallow, barley, fallow, wheat | 50 | 1.8 | 393 | 28 | 0 | 17 | 300 |

$\frac{1}{}$ 1 donum = 2 500 m²

- iv) Studies, investigations and reclamation work in the Tanouma Basrah, in the lower basin of the Euphrates, were carried out from 1967 to 1970. The soils were heavy textured, very highly saline and the lime content varied from 30 - 35%. Reclamation and leaching of these soils was not a problem and no amendments were needed except for the application of organic matter after leaching to increase soil fertility and improve structure.
- v) Studies and investigations in Hawejah project, representing the northern foothills, took place from 1968 to 1970. The soils were of medium texture, highly saline with 20 - 25% lime content and had a high water table. Good results were achieved from leaching and reclamation. Organic fertilizers had to be added to improve the soil properties and increase crop yields.
- vi) Studies were carried out (1971 to 1972) on the effectiveness of drains in the Khalis project (Mesopotamian Plain). Three sites were selected for the study. The depth of the drains was constant (1.8 m) but the distance between them was varied.
 - a) In Sodirah the soils had a fine texture and were badly structured. Salinity was low and the lime content between 23 and 31%.
 - b) In Masary the soils had a fine texture, bad structure, very low salinity and 27 - 31% lime.
 - c) In Abbassy the soils had a fine texture, bad structure, medium salinity and 23 - 30% lime.

No effect was observed on crop growth and land reclamation from salt affected soils with a lime content between 23 and 31%.

4.7. Results and Discussions

1) Results obtained from the experimental projects cited and from other regions in Iraq show that the presence of lime does not create noticeable problems in land reclamation and utilization. Lime is not found as hard formations either on the surface or in the soil profile and this may be due to the presence of a high salt content and the consequent effect on solubility of lime and its leaching to lower horizons.

2) The studies carried out in Abu Ghraib (1964-1966) showed that lime is an important factor in phosphorus fixation. Plants were unable to utilize all the applied phosphorus in the first year. The residual effect remained for two years or more.

3) No studies have been made on the effect of lime on the availability to plants of nitrogen and potassium; there is a need for such studies.

4) No studies have been made on the effect of lime on the physical properties of Iraqi soils. It is to be expected that in the presence of CaCO_3 , the soil moisture retention would be less, the hardness would increase and the porosity, permeability and availability of water would be less. These characteristics need investigating under Iraqi soil conditions.

Ideal utilization of the land resources calls for thorough investigations and studies based on survey, classification and evaluation of the soils to select those most suitable for vertical expansion and those requiring improvement for horizontal expansion. Such improvement and expansion would require the following:

- i) Priority being given to soils highly responsive to reclamation and to those costing less and giving higher returns at a faster rate. Such soils could provide savings which would then be used for further development of new lands and improvement of degraded soils.
- ii) The establishment of specialized agencies and organizations to carry on the responsibilities of land reclamation. In such organizations, an integrated approach to planning, execution, management and research should be assured.
- iii) The certain availability of irrigation water (surface or groundwater), which is the limiting factor in soil reclamation, development and crop production. The use of the appropriate irrigation method, allocation of the right amount of water needed for the developed areas and knowledge of crop water requirements are also required.
- iv) The identification and supplying of agricultural machinery adapted to local conditions, together with technically trained staff for its operation and maintenance.
- v) Planning for the economic utilization of land resources through intensive farming and proper management of soils and crops.

4.8. Recommendations

Since most of the countries participating in this Seminar are in the arid and semi-arid regions where salt affected, waterlogged, sandy and calcareous soils are of wide occurrence, and each group has its own problems, it is necessary to:

- 1) cooperate and coordinate with each other and with the assistance of FAO to make full use of their available resources and experience;
- 2) support and strengthen the Regional Centre for Research and Studies on Arid and Semi-arid Zones, sponsored by the Arab League, and establish specific branches in different countries, as the need indicates;
- 3) support and develop training centres in land reclamation in some countries and specially the training centre for land reclamation in Iraq as a nucleus for providing trained staff for the region. The Government of Iraq is giving full support to this centre and funds have already been allocated for it in the development plan 1970-1974;
- 4) adopt a regional applied research programme on calcareous and sandy soils in cooperation with FAO and accelerate the implementation phase of the applied research programmes on salt affected and waterlogged soils. The requested experts and equipment should be made available to those countries which have already supported the programme including Iraq. The approved programmes are being executed in Iraq in cooperation with FAO;
- 5) follow up research activities and field studies on reclamation and utilization of reclaimed lands. There should be discussion of research results and these should be disseminated through regional symposia and scientific conferences.

The soil of Jordan has developed mainly from secondary rocks that differ in their geological composition and age.

Two main kinds of limestones: hard and soft, exist in Jordan. In addition, sandstone and calcareous sandstone form the crust of a small area in Jordan. The soils of the Jordan Valley have developed mainly from alluvial materials.

These factors in addition to low weathering of the rocks are the reason for the content of CaCO_3 in most of the Jordan soils. The percentage and distribution of CaCO_3 particle size vary in these soils according to their origin and their degree of weathering.

Four main groups of calcareous nature soils exist in the country.

5.1. Red Mediterranean Soil (Terra Rossa)

This group of soils has developed mainly from hard limestone which has been classified by geologists in the Ajlum series. These soils are red to brown with a clayey texture and a clay content of 35 - 60% and occasionally up to 70%. Most of the CaCO_3 is in the coarse fraction of the soil particles.

Chemical analysis of several hundred samples of these soils has shown that they are salt free with a base saturation of about 100% and pH of 7.8 - 8.2.

This group of soils form most of the uplands parallel to the River Jordan and cover an area of about 13 000 km^2 . They usually receive 250 mm/year rainfall in the south to 600 mm in the south west.

They are planted with crops, mainly under rainfed conditions. Barley and wheat are the major crops grown in the south; wheat and legumes in the winter and vegetables in the summer are grown in the central area. In the southern hills, wheat, legumes and summer vegetables are grown on the plains while most of the rough hills are covered with forest and fruit trees, mainly olives.

The main problems facing these soils are:

- a) The acceleration of soil erosion which is evident and is due to poor tillage practices, as a result of the misuse of modern farm machines.
- b) The necessity for water conservation, since almost all of them depend mainly on winter rain and there is a long drought period of about seven months.
- c) Their usually high potassium content and poor phosphorus with a narrow C/N ratio.

5.2. Steppe Soils

They comprise the bulk of soils in Jordan and cover about 80% of the country. They developed mainly from soft limestones (chalks and marl) which have been classified by geologists in the Balqa series.

These soils are brown to yellowish brown with a clayey texture containing from 35 - 60% clay. The CaCO_3 content ranges from 20 - 70% and is usually in both the clay and silt fractions.

Most of these soils are salt affected with an EC range from 1 mmhos/cm to 50 mmhos/cm and frequently to 200 mmhos/cm and an ESP range from 20 - 50. They receive an average annual rainfall of 150 mm to less than 50 mm and are mainly poor range lands, dotted with intensive agricultural areas where underground water is available.

The importance of these soils to Jordan's agricultural economy depends upon the discovery of more groundwater sources which could lead to an increase in irrigation water for the development of these soils; but salinity and sodicity problems would then have to be tackled.

5.3. Alluvial Soils

This group of soils are either alluvial or developed from alluvial material. The alluvial soils are formed in a very narrow strip on the banks of the River Jordan; other soils are developed either from lisan marl (kattars) or from materials developed from the surrounding hills and mountains. The latter soils form the main agricultural land in the Jordan Valley which will be discussed in this category.

These soils have a colour range from very dark grey to yellowish brown with a silty clay loam to clay texture. The CaCO_3 content ranges from 15 - 60% and the size distribution varies according to the origin of the soils.

Their chemical analysis reveals the wide variation in their salinity, the trend of which increases from 1 mmho/cm in some northern areas to as high as 50 in the south. In many cases, salinity is mainly due to waterlogging sodicity which is of minor importance with ESP usually below 20.

These soils covers about 50 000 hectares, 15 000 of which are under intensive irrigation and this area is planted mainly with off-season vegetables, citrus and banana.

The main problems of these soils are:

- a) The rise of the water table in certain areas which was caused by both over-irrigation and the lack of proper drainage systems.
- b) The fertility status of these soils must be studied more comprehensively. In general, most of them are rich in potassium and poor in phosphorus.
- c) Chlorosis in many of the crops, and particularly in citrus, is evident and might be due to a high CaCO_3 content in addition to over-irrigation and some other factors.

The Agricultural Research Department is concerned with this problem and investigations are being carried out to find solutions.

6.1. Introduction

The problem of calcareous soils in Lebanon has been taken into consideration since the phylloxera invasion which started in our vineyards in the 1930s. The first function of the soil laboratory at the Agricultural Research Institute at Tel Amara was to estimate the calcium carbonate content in the soil in order to select the best rootstock of vines. The soils were classified then by Billault according to their calcium carbonate content and their colour.

It is well known that the Lebanese mountains are formed by Jurassic and Cretaceous limestone of various hardness; Cenourian and Eocene are mostly formed by marl and soft lime deposition. This lime is an important factor in the soil formation which is considered of autochthonous and/or allochthonous origin. As a result of the variations in climate, the Bekaa valley shows nearly all kinds of calcium carbonate formations mentioned by Ruellan, 1970. In the mountainous region where slopes are steep, the erosion is very active and the soils are shallow. Recently, in the last five years, soil scientists in Lebanon have become more aware of the problems of the management of these soils. Teamwork by soil scientists from the Lebanese Research Institute with the cooperation of the Litani Office, the American University of Beirut (AUB) and FAO started a research programme as follows.

6.2. Soil Survey

The first step of the research programme was the classification of the soils. In collaboration with FAO soil surveyors, the soils were classified according to their physiographic characters, especially for irrigation purposes. The most important factors considered were the depth of soil, the lime content, the texture, the colour, the slope and the presence of stones and gravel.

In the south of Lebanon four soil series were distinguished according to their calcium carbonate content:

1. Series with less than 10% active CaCO_3
2. Series with 10 - 20% active CaCO_3
3. Series with 20 - 30% active CaCO_3
4. Series with more than 30% active CaCO_3

The Lebaa Station has been established recently to conduct research on the management of calcareous soils of the second and third types of the above classification.

6.3. Soil Physics

With the collaboration of ORSTOM experts, the actual research programme deals with the hydrodynamic properties of the soils, the conception of R.U. (réserve en eau utile), the evolution of structure of soils under irrigation and the relationship between the water holding capacity and the lime content in the silt and clay fractions, considering at the same time the type of clays present.

6.4. Soil Chemistry and Fertility Programme

A joint programme with the collaboration of AUB on the application of soil mineralogy to the management of soil fertility has been initiated. The soil mapping units have been studied according to their physical, chemical, and mineralogical properties. The amount of active and total calcium carbonate in each soil mapping unit was related to phosphorus fixation. The recommendations for fertilizers, irrigation and other soil management practices are based on the fact that soils of common mineral composition have the same physical and chemical properties.

Studies on phosphorus forms, phosphorus retention and the fate of added phosphate fertilizer were done on selected calcareous soils. The effect of amorphous materials present in calcareous soils was also studied in relation to phosphorus fixation. Methodology is being stressed to devise or modify existing methods to fit calcareous soils. In other words, we are studying the applicability of laboratory methods in relation to field conditions. Already modified methods have been published for ammonium, potassium and phosphorus fertilization for calcareous soils. Research is now in progress to study the use of chelates, reducing agents such as hydroquinone, organic matter and minor elements in relation to yield on calcareous soils.

Another part of this programme is the availability of nutrients and the antagonism of calcium - potassium.

In addition to the above collaborators, an UKSTOM expert is studying the effect of organic matter in relation to soil structure and yield on irrigated calcareous soils. In the field a set of lysimeters was also established to study the evolution of soil structure and mobility of calcium carbonate in drainage water.

Laboratory research has also been initiated using soil columns leached with distilled water. The mobility of CaCO_3 is compared with that obtained in the field by lysimeters.

6.5. Clay Mineralogy

The mineralogy of 48 profiles covering the most important agricultural soils were identified. The lowland north of Tripoli was mostly montmorillonitic. Nine of the soils have a high kaolin content from the central Bekaa valley, south east of Tripoli, and the southern part of Lebanon. Central Bekaa, south Bekaa and north of Tripoli also showed weak kaolin contents.

Illite, vermiculite and chlorite were also identified in the above profiles with various concentrations in addition to kaolinite and montmorillonite.

6.6. Soil Irrigation and Agronomy

Tel Amara irrigation department, in collaboration with Litani and FAO scientists are studying water management practices, irrigation methods (sprinkler, furrow and drip irrigation), water need and water distribution.

Modern meteorological equipment is already installed to collect data for evapotranspiration studies.

Agronomists are trying to select the best varieties of forage, vegetables and fruit tree crops giving the highest yield on calcareous soils.

PART I: Genesis and Classification of Calcareous Soils
in Jebel El Akhdar

7.1. Introduction

The Jebel El Akhdar occupies the greater part of Northern Cyrenaica and is roughly 250 km long, east to west. To the south and the east the ground falls away very gradually but the northern part is delineated by two steep escarpments.

All the exposed rocks of the area are sedimentary and are mainly marine limestones. The oldest are Cretaceous and the youngest Marine Pleistocene, but most of the area in question must be regarded as composed of Eocene with subsidiary Miocene.

7.2. General Conditions

The Jebel El Akhdar is a mountainous region which consists of two plateaux running parallel to the seashore. Its annual rainfall varies between 300 - 600 mm.

The lower lying plateau has an elevation between 200 - 400 m. The upper plateau, whose elevation varies from 500 - 700 m is extended southward by a higher zone with a gradual transition and reaches 876 m at its highest point; this latter zone is sometimes called the third plateau.

The upper plateau is composed of Oligocene and more rarely Miocene limestone formations. The substratum is either hard limestone on which are found ferro-siallitic soils, or chalky limestone associated with rendzinic or with brown limestone soils, or marls covered with very clayey vertic soils.

The landscape consists of hills covered with vegetation like Pistacia lentiscus, oleasters, Cypressus phlomis, Cistus. These vegetal species are replaced by a herbaceous cover of Artemisia herba alba south of the 300 mm isohyet.

The lower plateau is made up mainly of older (Eocene) covered hard limestone, which is affected by an intense karst erosion related to the dissolution of the limestone.

The limestone massifs are deeply eroded. The intense fissuration of the hard limestone facilitates the penetration of water and the surface of the karst is broken up and contains many pockets and shafts in which the shrubs, Juniperus phoenicea, Pistacia lentiscus and oleasters develop their root system.

The alteration of limestone is most often a red decarbonation clay terra rossa on which ferro-siallitic soils are formed and sometimes a yellow decarbonation clay or terra fusca on which brown ferro-siallitic soils are formed.

7.3. Climatology

The Mediterranean climate characterized by rain in winter and a dry season in summer may be subdivided in two Mediterranean bio-climates:

1) Sub-Humid Mediterranean Bio-climate

It is characterized by an average rainfall greater than 500 mm and an average temperature of 18°C. This bio-climate corresponds to the upper plateau.

2) Semi-Arid Mediterranean Bio-climate

Average annual rainfall is between 300 and 500 mm and average annual temperature is about 19°C. This bio-climate corresponds to the lower plateau.

7.4. Principles of Soil Classification

Soils are classified according to the French classification: reference "Travaux de la Commission de Pédologie et Cartographie des Sols" 1947 Edition: Institut National de la Recherche Agronomique.

The major units are the following: Class, Sub-class group, Sub-group.

The calcareous soils in Jebel El Akhdar are classified under the class of calcimagnesian soils.

7.5. Class of Calcimagnesian Soils - Sub-class of Carbonated Soils

These soils are characterized by the presence of alkaline earth ions and, in particular, of calcium carbonate. The profile is of the type AC or A (B) C, without there even being a horizon B. In the horizon A, the organic matter is closely related to the mineral elements and forms a very stable complex with them. The complex is saturated with calcium and secondarily, with magnesium. The pH is basic and always greater than 7.0. The structure is granular and finely polyhedral.

The sub-class of the carbonated soils includes the following groups.

7.5.1 Group of rendzinas

These are carbonated calcic, thin 20 to 40 cm soils having a clearly granular or finely sub-angular structure often including limestone pebbles. The parent material consists of a carbonated rock.

Example : Profile (Sidi Gharib)

Landscape

and

Vegetation: Plateau with small slope, cereals.

Description

0 - 30 cm: Brown, 10 YR 8/4, sandy clay loam, vigorous effervescence, granular, loose, low consistency, fresh, many roots.

30 - 50 cm: Yellowish white with rusty and ochre passages. Beds of limestone in plates mixed with friable, powdery limestone.

The rendzinas are particularly suitable for cereal farming. The chalky substratum is a favourable element for water retention in depth and crops can benefit from an additional water reserve stored by this subsoil. Also, it is to be recommended that the sterile chalky substratum should not be raised and that crops sensitive to chlorosis should not be grown.

7.5.2 Group of calcareous brown soils

These are calcic carbonated soils having a structural horizon (B). Two sub-groups are distinguished:

- (a) Calcareous brown soils
- (b) Vertic calcareous brown soils

(a) Model calcareous brown soils

Example : Profile (Al Haj Younis)

Landscape and Vegetation : Plateau, cereals.

Description

- 0 - 30 cm : Dark brown, 10 YR 3/4, clay loam, vigorous effervescence, grumous low cohesion, low consistency, fresh, quite numerous roots.
- 30 - 50 cm : Greyish brown, 10 YR 4/3, clay, vigorous effervescence, sub-angular, low cohesion, average consistency, fresh, quite numerous roots.
- 50 - 80 cm : Light grey with white stains 10 YR 4/2, clay loam, vigorous effervescence, transition horizon, low cohesion, average consistency, fresh, some roots.
- 80 -100 cm : Chalky limestone, powdery and friable.

The calcareous brown soils are rich in organic matter (3 to 4%), well structured on the surface and generally thicker than the rendzinas.

(b) Vertic calcareous brown soils

This sub-group corresponds to agrillaceous calcareous brown soils in which the subsoil exhibits vertic characteristics, polyhedral to prismatic structure, presumably with swelling clays having a high exchange capacity.

Example : Profile (Al Haj Younis)

Parent Material : Marl

Landscape and Vegetation : Hilly plateau, cereals

Description

- 0 - 20 cm : Yellowish brown, 10 YR 4/3, clay, vigorous effervescence, grumous structure on surface, then sub-angular, coherent, pasty consistency, fresh, not many roots.

20 - 100 cm : Yellowish grey, 10 YR 5/4, clay, vigorous effervescence, polyhedral, shiny slip faces, coherent, pasty consistency, fresh, few roots.

100 cm : Yellowish marl with small friable calcareous nodules.

These carbonated soils are characterized by their high clay content, their poor structure and their compactness. These characteristics are reflected in poor internal drainage, the permeability rate is low, $K = 0.9$ cm/h.

The vertic calcareous brown soils are difficult to work owing to their compactness in the dry state and their plasticity in the wet state. Consequently, this land is difficult to improve and must be tilled taking into account its wet condition.

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7.6. Introduction

The soils of Cyrenaica are mainly calcimagnesian.

These soils have the common characteristics of a fine clay loam or very fine clay texture and a basic reaction (pH higher than 7.5) when they are decarbonated. They are therefore susceptible to chlorosis especially as the limestone content is high. This should be taken into account when choosing crops.

The soils of Cyrenaica have a low phosphoric acid content and the ferro-siallitic soils are deficient in this element.

As the majority of the soils are of a carbonated or calcic nature with a calcium saturated complex, the conditions for their use and fertilization are given below.

7.7. Chemical Fertility

7.7.1 Nitrogen fertilization

Calcareous and calcic soils nitrify easily but the nitrates are mobile and carried down into the soil. It is therefore necessary to add nitrate fertilizers in accordance with requirements and with the vegetative cycle of the crop. Suitably placed ammonium sulphate appears to be more valuable than nitric fertilizers.

7.7.2 Potassium fertilization

The sharing of the K ions between the soil and the plant is related to the nature of the clay. Ferro-siallitic soils consist mainly of montmorillonite and of some illite.

A small part of the potassium in the montmorillonite remains available for the plant (potash retro-gradation phenomenon).

Thus even in a soil sufficient in exchangeable potassium, the nutrition of the plants depends upon the liberation of the non-exchangeable potassium.

In the case of the soils of Cyrenaica, the potassium migrates slowly and the open-structured clays retain the K ions. Potash requirements are relatively high and it is necessary to apply fertilizers as required by the crops.

7.7.3 Phosphate fertilization

In a calcareous soil, phosphorus can be insolubilized in the form of calcium phosphate. Ferro-siallitic soils are deficient in this element. The insoluble phosphorus in the calcium phosphate can be liberated by adding organic matter and this explains the higher P_2O_5 content in calcareous or mollic brown soils. However, the P_2O_5 content always remains rather low.

Phosphate requirements are high and it is recommended that the fertilizer be applied in doses, the least soluble fertilizer in the autumn and the most soluble (e.g. super phosphates) at the end of the winter.

7.7.4 Organic fertilization

Ferro-siallitic soils have an organic matter content of less than 2%. The addition of organic matter in the form of green fertilizers or manure is beneficial, not only on the structure of the soil, but also on the solubilization of the phosphates and of the oblige elements, such as boron.

7.8. Deficiencies and Chlorotic Power

Since many of the soils of Cyrenaica have a pH of 8 magnesium, phosphorus and boron are made less soluble or insoluble.

The consequences can be deficiency diseases and the frequent appearance of chlorosis. The reaction of the plants appears to reflect the chlorotic power of the soil better than its active limestone content.

In fact, the pH is not the cause, but the indication of a set of conditions.

Chlorosis is manifested by the yellowing of the leaves of plants which begin to wilt. Iron can no longer be absorbed by the plant for reasons related to the nature of the soil.

Crops which are not highly sensitive to chlorosis should be chosen or if plants show signs of chlorosis they should be treated by spraying with ferro or ferro-silixic complexes of the EDTA type.

7.9. Erosion

The soils of Cyrenaica and, in particular, those which are located in Jebel el Akhdar, are subject to erosion owing to the uneven relief and the nature of the rainfall.

Sheet erosion is evident on the gentler slopes (beginning at 1%) when the soil is bare and gully erosion on slopes (beginning at 3%) void of vegetation or cleared. Therefore, in order to prevent erosion, it is essential that clearing should be carried out with caution.

It is also recommended that the natural vegetation between the cleared parcels should be maintained in order to create a wooded landscape with woody slopes intended to slow down erosion and to serve as windbreaks.

8.1. Introduction

West Pakistan lies between latitudes 23° and 37° north and longitudes 61° and 76° east. Its total area is about 810 000 km² and population about 60 million. There are three main physiographic units: (i) the mountainous area, (ii) the Indus plains and (iii) the Thar desert. The mountainous area covers more than two-thirds of the country on the northern and western sides. The Indus plains extend over an area of about 207 000 km² whereas the Thar desert, which is a vast region of sand ridges, covers about 65 000 km².

8.2. Climate

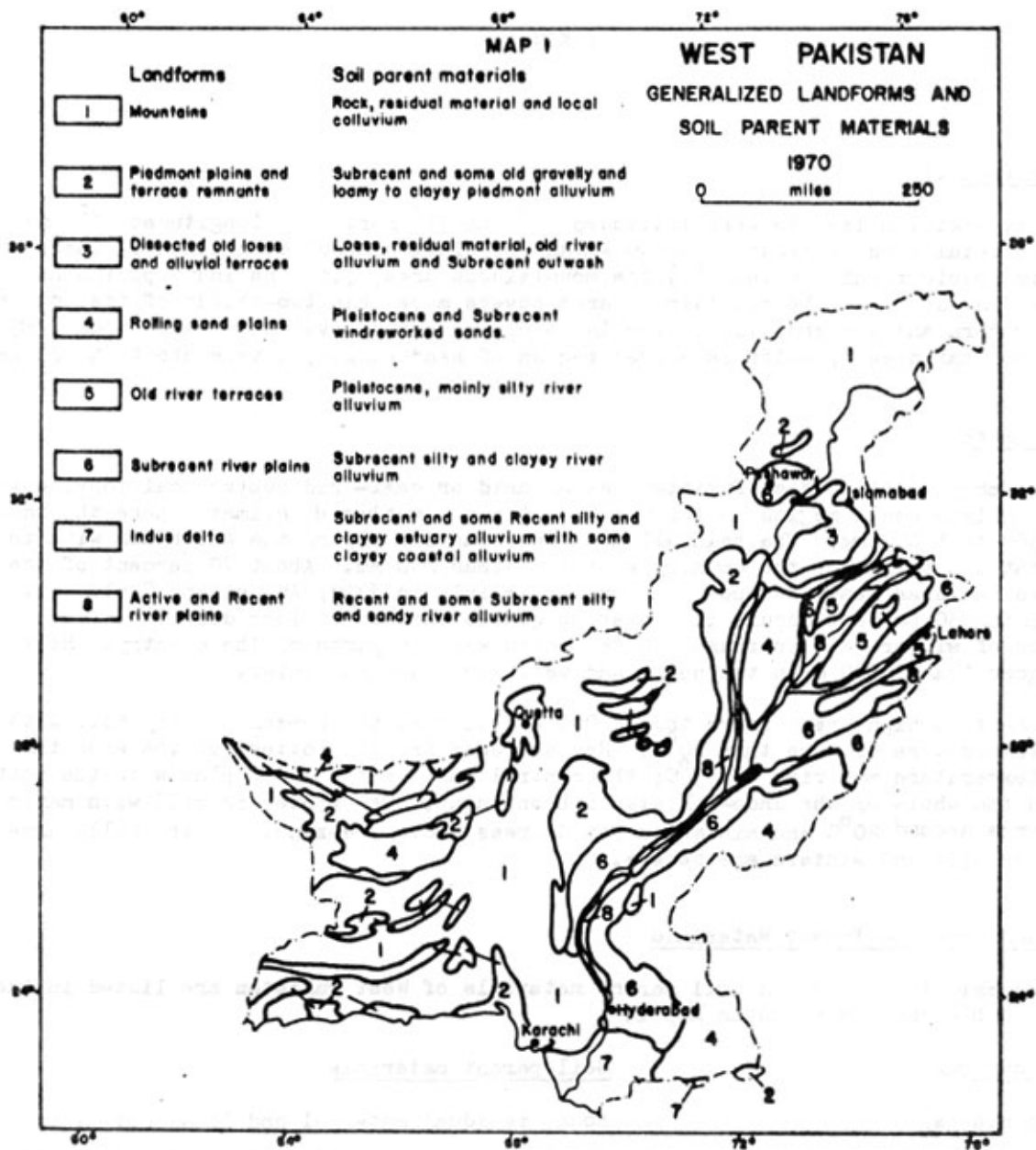
The major part of West Pakistan has an arid or semi-arid subtropical continental climate. Only a small region in the north-east has a subhumid climate where the rainfall is 500 to 1 000 mm. The rainfall decreases rapidly toward the south-west with the result that two thirds of the country gets less than 200 mm. About 70 percent of the total rain falls as heavy downpours in summer, mainly in July, August and September. The remaining 30 percent occurs in winter as gentle showers of long duration. The proportion of winter rain increases in the north-western parts of the country. Hilly areas higher than 2 000 m in the north and west have snow in winter.

Except in high areas (more than 2 000 m altitude) the summer is very hot, with a maximum temperature of more than 40°C . May and June are the hottest months when the maximum temperature may rise to 45°C ; the central part of the Indus plains is the hottest region in the whole of the Indo-Pakistan subcontinent. The winter is mild with maximum temperatures around 20°C and minimum a few degrees above freezing. In the hilly areas summers are mild and winters are severe.

8.3. Landforms and Parent Materials

The main landforms and soil parent materials of West Pakistan are listed in the following table and are shown in Map I.

| <u>Landforms</u> | <u>Soil parent materials</u> |
|--|---|
| 1. Mountains | Rock, residual material and local colluvium |
| 2. Piedmont plains and terrace remnants | Subrecent and some old gravelly and loamy to clayey piedmont alluvium |
| 3. Dissected old loess and alluvial terraces | Loess, residual material, old river alluvium and Subrecent outwash |
| 4. Rolling sand plains | Pleistocene and Subrecent wind-reworked sands |
| 5. Old river terraces | Pleistocene, mainly silty river alluvium |
| 6. Subrecent river plains | Subrecent silty and clayey river alluvium |
| 7. Indus delta | Subrecent and some Recent silty and clayey estuary alluvium with some clayey coastal alluvium |
| 8. Active and Recent river plains | Recent and some Subrecent silty and sandy river alluvium |



Each landform is briefly described below:

8.3.1 Mountains

This mapping unit occurs over a large area in the western and northern parts of West Pakistan. The whole area has been subjected to folding, faulting and uplifting as a result of compression between two stable land masses - one in the north in China and the other in the south in India. During the Mesozoic and Tertiary periods, almost the whole of West Pakistan was part of a great depression forming an extensive sea which received sediments from the rising hill ranges in northern Afghanistan and along the northern borders of Pakistan and India. The western and northern strips of this sea area in West Pakistan received mainly sandy, calcareous, near-shore sediments. The central strip received mainly silty and clayey sediments with lime, and deposits of dark-coloured (near-surface) and reef limestones. The south eastern strip is mainly massive or bedded white limestones, indicating deposition far from the source of continental sediments. At different times during the folding, igneous material was injected into the centre of the folded areas, giving rise to the mainly granitic core of the Himalayas and spots of volcanic rocks of different ages.

During the Tertiary, the compression of this area continued, causing folding and uplifting of progressively more southerly and younger sedimentary rocks. Some folding and faulting continued during the early Pleistocene. As a result, all the area formed mountain ranges and only the present Indus plains remained under sea.

The mountains have steep slopes covered with scree or colluvial material on their lower parts. The main rocks are limestones and calcareous shales and sandstones. In humid areas in the north the valleys are 'V' shaped as the rivers and streams are still engaged in active down-cutting. In the arid parts in the west the valleys are filled with alluvium. Hard limestones weather slowly and yield little material. Therefore, much of their surface is bare rock, except for some material in depressions and crevices. Sandstone and shale mountains have much less exposed rock and a much higher proportion of scree and colluvium.

It is worth noting that although the rocks and the structure of the mountains are mainly Tertiary or older, the land surface and the soils are generally Holocene, part Pleistocene, due to continued erosion.

8.3.2 Piedmont plains and terrace remnants

This mapping unit occurs in the western mountainous area of West Pakistan and consists of three main elements: loamy and silty, very gently sloping plains; clayey, part strongly saline basins; and stony, sloping fans and valley margins. In many places there are remnants of the same main elements from an earlier cycle of deposition, occurring as generally stony terraces. All the materials are strongly calcareous.

8.3.3 Dissected old loess, residuum and alluvial terraces

This mapping unit comprises the Potwar uplands: a vast area of deeply dissected loess and alluvial terraces with Subrecent outwash and residual material outcropping in ridges or valley bottoms or occurring as broad interfluves. A small area in the northern part of Peshawar Vale has a similar, but less complete landscape of loess and alluvial terraces. On the map, this could not be shown due to its small extent. The same is the case with small patches of loess in some other places. Loess is among the oldest of the main soil-forming sediments recognized in West Pakistan. In the Potwar uplands it forms a vast, deeply dissected sheet which may overlie older alluvium, locally older loess or piedmont or, unconformably, mainly steeply dipping Tertiary rocks. The loess is estimated to have been deposited in the main, coldest, period of the last glaciation - say, some 50 000 to some 20 000 years ago. As in other loess areas of the world, except for the most arid parts, the material appears to have been blown out of broad, sandy river beds and river plains downstream (the area of the present Indus plains).

8.3.4 Rolling sand plains

Wind-reworked sands occupy a considerable part of West Pakistan. The main area is the desert of Cholistan and Thar, a band about 80 km wide, over a distance of some 805 km in the southeast, along the Indian border. This forms the western margins of the Rajputana desert of India. The origin of the sands is not certain. They are most probably older than the last Glacial period, in view of their elevation far above the probably levels of the Indus and Sutlej courses in the late Pleistocene. The landscape consists of mainly stabilized hilly sand plain, with longitudinal ridges in the south but alveolar (honeycombed) and transverse ridges in the northern part. The sands are calcareous, rich in weatherable minerals and typically yellowish or pale brown. They contain less mica but more quartz than the sands of the Indus river and its tributaries.

In the north, the sandy area of Thal, between the Indus and Jhelum rivers, is an old Indus terrace deposited in the later part of the last Glacial period. The sand ridges are longitudinal, transverse and alveolar, which are stabilized with vegetation.

The western areas of wind-resorted sands are also of alluvial origin: sandy piedmont slopes, probably of Holocene and partly of late Pleistocene age. In the arid climate of this part of West Pakistan, soil development is virtually nil, the vegetation covers less than some two percent of the total area and reworking by wind is continuing.

8.3.5 Pleistocene river terraces

During the main part of the last glaciation, shallow seasonal surface thawing in the permanently frozen uplands liberated large amounts of sand from Tertiary and Pleistocene sandstones, and the sandy material was deposited probably all over the present Indus plains, but at present, the sandy terrace base is at the surface only north-east of a line running northwest of Lahore. Further southwest it is buried under deposits of the later part of the last glaciation when the permafrost in the uplands and Himalayan foothills disappeared and enormous quantities of unconsolidated sediment, mainly loess and some old silty and sandy alluvium, were removed from there by deep and widespread dissection. This mainly silty material was deposited on the sandy terrace base. Its thickness increases from very thin near Lahore to more than 7.6 m near Multan. The surface of this deposit is now some 6 m above the present river plains in the north-eastern part and merges with the river plain near Multan. Further downstream it is presumably buried under increasing depths of later sediment.

During the early Holocene, wide plains were cut by the rivers in the old sediments along their courses, so that steep-edged Pleistocene river terraces now remain in the centre between each pair of rivers.

8.3.6 Subrecent river plains

Covering the Indus and tributary river plains, this mapping unit mainly consists of silty levees, clayey basins and sandy meander bars with a silty cover of varying thickness.

During the early Holocene, a somewhat warmer and more humid climate than the present caused a denser vegetation in the Himalayan foothills and uplands, with consequently less erosion and larger, more constant, river flows with less sediment load. The Pleistocene river deposits in the upper Indus plains were dissected, producing the broad Holocene river plains between the remaining strips of old terraces. The depth of dissection in the north-eastern part of the West Pakistan plains was of the order of 6-9 m, diminishing downstream due to the difference in gradient. Near Multan, the Old and Subrecent river plains are at about the same level, and further south-west the Subrecent river plain was built up over the late Pleistocene level, due to the rise in sea level and the sediment added to the rivers by the dissection upstream.

During the middle and late Holocene, the sea level remained constant and the climate was much like the present, with less rainfall than during the early Holocene. Some decrease in vegetative cover in the uplands due to the decreased rainfall brought about a

slight increase in erosion and increased seasonal changes in river flow. This is probably the cause of the presence, even in the northern Indus plain, of large areas of double storey soil profiles, in which soil formation was interrupted by accretion of some 0.6 - 0.9 m of new sediment and followed by soil formation mainly in the younger sediment. In the lower Indus plain, vertical accretion continued, but at a slower rate than during the early Holocene, and with periods of soil formation in areas where the river was not currently depositing sediments.

8.3.7 Indus delta

The estuary plain differs from the river plain in four main characteristics. Its gradient is considerably smaller; it contains a large proportion of extensive, level, silty spill flats; it has a different degree and kind of salinity; and the river channels in the natural landscape are distributaries influenced by sea tides.

The main part of the estuary plain consists of very extensive, level, saline, silty spill flats and level, part saline and part nonsaline, clayey basins and channel infills. Narrow, nonsaline silty levees, which overlie the estuary material, extend along some Indus distributary channels far into the delta from the boundary of the river plain.

The coastal fringe mainly consists of extensive, strongly saline, silty clay tidal flats with some narrow, slightly higher, strongly saline, silty tidal ridges.

8.3.8 Active and Recent river plains

The Active and Recent Indus floodplain in the northern half mainly consists of sandy bars and levees with gentle slopes away from the multiple and relatively shallow river courses. Locally, small areas have a shallow clayey or silty cover which is nearly level. The Active and Recent floodplains of the eastern tributaries generally have a large proportion of nearly level, shallow to moderately deep, silty covers and a smaller area of uncovered sandy meander bars and levees. The Indus course in the southern half is intermediate between these two conditions.

8.4. Calcareous Soils

Calcareous soils of West Pakistan have been broadly grouped into four classes as shown in Map 2 and are described below.

8.4.1 Moderately calcareous soils of the Indus Plains

These soils cover almost the whole of the Indus Plains (about 200 000 km²) which form about one fourth of the total area of West Pakistan. They have formed in calcareous alluvial material which is derived from the calcareous rocks of the Himalayas and deposited by the Indus river and its tributaries. The alluvium is moderately calcareous when it is deposited, and contains about 8 to 12 percent lime. The climate is arid or semi-arid and, therefore, little leaching takes place. Moreover, the soil formation has taken place concurrently with deposition of new alluvial material. This has also maintained the original calcium carbonate content of the soils. The lime is present mostly as silt size particles, very little lime being present in clay size or sand size.

The soils show structural development, with angular or subangular blocky structure, accompanied by accumulation of well humified organic matter, down to about 100 cm depth. The original fine stratifications which are characteristics of fresh alluvial deposits, have disappeared during structural development and homogenization.

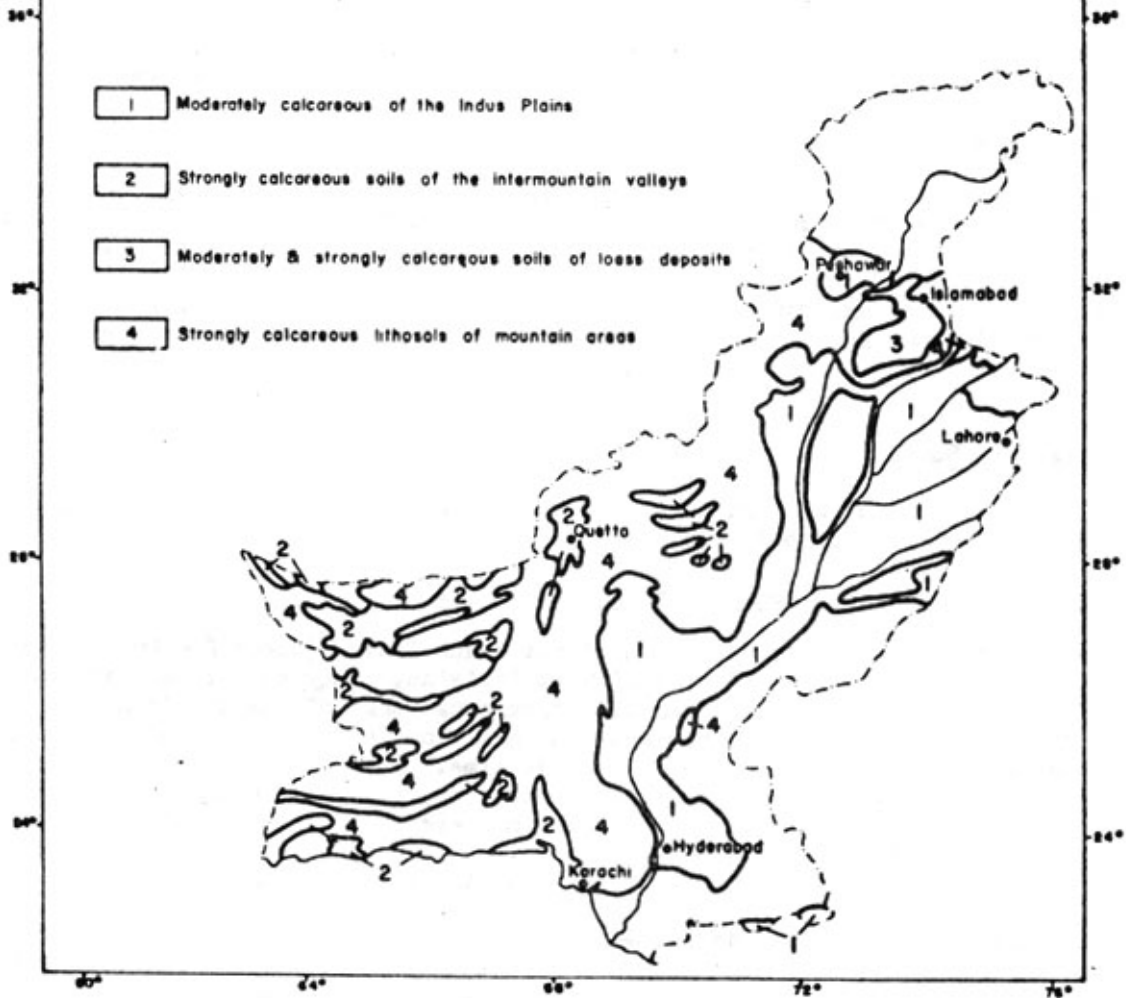
A part of these soils in the northern Indus Plains are developed on Late Pleistocene river terraces and show a lime profile with a zone of lime accumulation. The climate

80° 64° 68° 72° 76°

MAP 2

WEST PAKISTAN
CALCAREOUS SOILS

0 miles 200



of this part is semi-arid and some leaching of lime has taken place, so that the soil up to about 120 cm contains only 5 to 8 percent lime and is underlain by a zone of lime accumulation which contains about 15 to 20 percent lime both as fine particles and lime nodules. Only in very small patches the zone of lime accumulation starts within 50 cm of the surface.

The greater part of the area of these soils in the central and southern part of the Indus plains are formed in Subrecent deposits. These soils contain lime evenly distributed throughout the soil profile. There are some fine lime concretions in some soils but they occur throughout the subsoil and do not form any zone of lime accumulation.

The texture of these soils is mostly loamy (silt loams, loams and silty clay loams) and clayey; the proportion of the latter increase in the southern part of the Indus plains. The content of organic matter, present in well humified form, varies between 0.4 and 0.7 percent, and the pH of the soil is about 8.2. The exchangeable sodium is high only in a comparatively small part of the total area but locally quite important.

These soils form the most important agricultural land of West Pakistan and are very productive for a wide variety of crops. The presence of calcium carbonate in these soils poses only minor problems of plant nutrition, as for instance the availability of phosphate, iron, manganese etc. Probably the presence of well humified organic matter (0.4 to 0.7 percent in the soil profile down to about 100 cm depth) helps to overcome the harmful effects of calcium and magnesium carbonates and the problem does not become acute. Farmyard manure added to the soil by farmers once in three or four years also helps to overcome the harmful effects of calcium carbonate to a considerable extent. Vegetables and fruit orchards are given farmyard manure in quite heavy doses. This practice helps to control deficiencies of minor elements and phosphate. Vegetables and fruit trees planted in new areas sometimes show symptoms of deficiencies of minor elements but these generally disappear after a few years of farmyard manure applications.

With the increasing use of nitrogen fertilizers, deficiencies of phosphate have become pronounced during the last few years, effecting especially pulses and other legumes as well as tuber crops like potatoes and sweet potatoes. The farmers have reduced the area under these crops.

It seems that in the fertilizer programmes of such soils addition of organic matter is essential, especially for vegetables and fruit trees. For field crops the use of artificial fertilizers is generally helpful in producing enough root material to raise organic matter content of soil, and if a part of the plant residue (like wheat straw) is also buried in the soil and some nitrogen is added to encourage its decomposition, it is very useful. Some progressive farmers have already adopted this very practice.

Only in small areas, where the zone of lime accumulation is within 100 cm, fruit trees do not grow well, as the lime zone is massive and probably contains a high proportion of active lime. The lime concretions also act as a mechanical hinderance to root development.

8.4.2 Strongly calcareous soils of the intermountain valleys

Covering about 62 000 km² in the western hilly area of West Pakistan, these soils occupy valleys and basins. They are formed in alluvial deposits derived from limestone and calcareous shales and sandstones as well as loess. The deposits have a piedmont character. Typically, gravelly materials occur near the mountains and form borders of the valleys and basins. Next to the gravelly deposits there are loamy or silty deposits and in the lowest parts there are clayey deposits. Generally, the loamy deposits are most extensive and form important agricultural soils. The soils are strongly calcareous and contain about 20 percent carbonates of calcium and magnesium, mostly as silt-size

particles. As the climate is arid or semi-arid, no leaching of lime has taken place. The soil formation processes are limited to homogenization and weak structural development. Organic matter present in well humified forms is very low, generally 0.4 to 0.5 percent.

The greater part of these soils is used for grazing sheep, goats and camels. Only a small part is cultivated with irrigation from groundwater which is usually present in the gravelly deposits on valley margins. The water is taken through underground tunnels which are made by connecting series of wells. Flowing by gravity the water appears at the surface on the loamy part of the valleys. The water tunnels are called 'karezes' which are analogous to 'ghanats' in Iran and 'phagaras' in Iraq and Jordan. A variety of crops and fruits is grown under irrigation. Addition of farmyard manure consisting of dung of sheep, goats and cattle is a standard practice for fruit orchards and vegetables. Newly planted fruit trees often show chlorosis, the sign of iron, manganese and zinc deficiencies, but it is seldom seen in older orchards which receive regular applications of organic manures. Field crops like wheat, alfalfa, melons etc., which receive occasional applications of farmyard manure, grow quite well.

Parts of these soils are used for growing wheat, sorghum and melons with torrent flood waters. The fields are made with high embankments and are soaked with a deep irrigation whenever torrent water is available. Since the success of the crop depends upon the moisture in the soil, fertility is not a problem and no manuring is done.

8.4.3 Moderately and strongly calcareous soils of loess deposits

Loess deposits occur in the northern part of the Indus Plain and cover about 13 000 km². The deposit pertains to the last glaciation period and is strongly calcareous, containing about 20 percent carbonates of calcium and magnesium. Soil formation took place during the Early Holocene but at the same time large-scale erosion occurred, so that only a very small part of the area has fully developed soils which have escaped erosion. The fully developed soils are non-calcareous with clayey or clay loam B horizons and loamy surface soil. Most of the area is, however, occupied by a soil which has developed on an erosional surface and has a thin B horizon with weak or moderate structure. The erosional surface comprises the zone of lime accumulation of the original soil. The soil is moderately calcareous to about 30 to 50 cm, but strongly calcareous below and also contains concretions of lime.

The other important soil consists of massive loess material in its original form and is strongly calcareous, with about 20 percent lime.

The two soils occur in an association which comprises gently to moderately sloping areas of the moderately calcareous soil in high parts and massive loess soil in dissected, low areas. The association also includes areas of gullied land and bad land.

Both of the important soils occur in a subhumid and semi-arid climate with mean annual rainfall ranging between 400 mm and 1 000 mm. They are used mainly for growing rainfed wheat and sorghum. The crops show quite good response to a combination of nitrogen and phosphate fertilizers. Comparative study of the fertility problems of the two soils has not been made.

8.4.4 Strongly calcareous lithosols of mountainous areas

These soils cover about 310 000 km² in mountainous areas of West Pakistan. The main rocks are limestones of various kinds and some calcareous sandstones and shales. The greater part of the area consists of steep slopes of bare rocks, whereas the remaining area has very shallow soils which are strongly calcareous. These soils occur in an

arid and semi-arid climate. The sparse vegetation on them is used for grazing. As the main problems of these soils are very shallow depth and steep slopes, the high lime content is not so important a limitation.

8.5. Other Soils

The uncoloured areas in the map have either non-calcareous soils or sandy soils. The non-calcareous soils occur in the northern parts of the country while the sandy soils occupy areas of rolling sand plains in the south and west.

9.1. Introduction

Soils in Qatar have not been studied. The area of Qatar State is about 1 million hectares.

The agricultural area is about 6 000 ha (0.52% of the country), and vegetables are the main product. Agriculture depends entirely on water from shallow wells. The possibility of expanding the agricultural area is limited by the available water resources and the lack of potentially productive land. Land productivity classifications show that Qatar soil can be considered of low productivity, due to the poor quality of the soils and water.

Qatar soils are classified generally as calcareous and these are problem soils as far as agriculture is concerned, which in turn may affect the agricultural economy of the country.

Qatar has been classified as arid region, where all agriculture depends on irrigation from groundwater. Some 1 500 shallow wells already exist. An area of groundwater (total dissolved salts 1 000 - 2 000 ppm, mostly of NaCl) exists in the central part of the Qatar peninsula and seems to be continuous in all parts of north Qatar. In the centre and south of Qatar, a good fresh water (T.D.S. up to 3 000 ppm) exists, but with equal amounts of chloride and sulphates and seems in most cases to be not interconnected. Usually the groundwater is from 3 to 20 metres below ground surface in North and Central Qatar. In the South, water may be as much as fifty metres below ground surface. Most of this water is used for agriculture and some of it is used for municipal purposes after it has been mixed with distilled water from the sea.

9.2. Distribution and Nature of Calcareous Soils in Qatar

The majority of calcareous soils in Qatar State are located in depressions formed from colluvium materials sedimented by the seasonal rainfall runoff on rocky limestone strata (bedrock), which is dominant in Qatar. These depressions are scattered along the Qatar peninsula forming oases in the desert.

In northern and central Qatar, calcareous soils are dominant in these depressions. In the south, calcareous sandy clay to calcareous sandy loam are the dominant soils, as they are also in the south-west of Qatar where a few sandy wadies have been formed by the transportation of desert sands. In the south-east of Qatar, sand dunes and sandy hills are formed on a rocky surface.

Salt affected calcareous and sandy soils are located adjacent to the Gulf shore and represent 6.04% of the Qatar peninsula area.

Calcareous soils mainly have high calcium carbonate, silt and clay contents with a moderately slow infiltration rate such as in colluvium depressions which are characterised by a limited soil depth overlying the bedrock, with low salinity. The thickness of the colluvium sediments in depressions provide a potential for the use of these soils. The dominant salts in these depressions are generally soluble calcium, magnesium and sulphates, with a low content of total soluble salts.

Saline soils are characterised by a high sodium chloride content, a saline water table and are adjacent to the sea.

The salt affected calcareous soils, of secondary origin in Qatar, are mostly in the present cultivated area. The deterioration of these soils is mainly attributed to the saline well waters used in irrigation and the misuse of irrigation water over the years, together with the lack of drainage system and soil management practices.

Qatar soils are characterised by low fertility, due to the arid climatic conditions.

9.3. UNDP/FAO Project - Hydro-Agricultural Resources Survey

Co-operation between the Government of Qatar and FAO on the project to study water and land resources, which was begun in 1970, will have valuable results on water availability and soil resources. That project includes the following:

- (i) A reconnaissance soil survey and land classification with the production of three maps: soil classification, land classification and potentialities, and soil index map, all at scale 1:100 000.

It has been interpreted that Qatar State can add about 26.4 thousand ha (2.4% of its area) for agricultural utilization, provided that water is available.

- (ii) The study of water quality and resources, in order to assess agricultural extension in the future programme.

9.4. Studies on Calcareous Soils

No study on soil capabilities had been conducted in Qatar prior to the present hydro-agricultural surveys project. The problems could be stated as follows:

- (a) The domination of calcareous soils in Qatar, plus limited soil profile depth over the bedrock.
- (b) The high content of CaCO_3 and magnesium carbonate in the soil
- (c) Soil compaction and low water penetration
- (d) Inefficient soil management and low soil productivity
- (e) The dominant arid climatic condition
- (f) Limited irrigation water depending on season rainfall run-off where it is recharged by shallow wells and with moderate to high salinity contents
- (g) Inefficient irrigation practices
- (h) Low fertility
- (i) Desalinisation of the present cultivated area.

The activities of the project were generally focused on the following points:

- (i) Interpretation of the area of arable soil available in the whole of the Qatar peninsula; chemical and physical characteristics of calcareous soils, their diagnosis, reclamation and management were delineated.
- (ii) Infiltration rate measurements were carried out on Qatar soils in the field by using an infiltrometer with one cylinder.
- (iii) A detailed soil survey and land classification of Qatar Government Farm was carried out in order to specify the major problems and delineate a specific programme on soil management and soil amelioration on the cultivated calcareous affected soils.
- (iv) A water survey was conducted by the hydrological section of the Project on water resources and availability.

9.5. Land Reclamation and Improvement

There has been no land reclamation and improvement except to a limited extent in some agricultural areas, where 30 cm of top soil have been transferred to cover the rock fragments for vegetable cultivation.

9.6. Recommendations

1. The study of Qatar soils should be encouraged, physically and chemically, and the establishment of the new soils laboratory which was essential and has now been completed must be supported.
2. The very detailed soil study on the present cultivated land, as well as a detailed survey on the potential arable land prior to its cultivation should be completed.
3. Work on soil conservation and erosion should be supported and a study carried out on forestry cultivation on saline sandy soils with particular attention being paid to the water table.
4. Benefits would be gained if a feasibility would be carried out on reclaiming saline soils where irrigation water is available.
5. The establishment of a regional research programme on reclaiming calcareous soils is necessary and would be of great benefit to the country.
6. Improvement of irrigation practices in Qatar State is necessary and measures to ensure this should be encouraged.

10.1. Introduction

The Kingdom of Saudi Arabia has a total area of about 225 million hectares and of this area just over 0.1 percent is under cultivation. The Government intends to double the present area under cultivation in the next 15 years, through survey and evaluation of land and water resources.

The variation in the soil forming factors prevailing in the country results in the existence of different soil types. Aridity and a hot climate, lack of water and wind erosion affect the degree of soil formation. Concerning chemical weathering of the soils, it proceeds at a slow rate owing to the absence of much rainfall and the soils therefore tend to be salty for the soluble products are not washed away. Less soluble salts such as gypsum and CaCO_3 exist in some soils in a considerable percentage. Generally, the organic matter content is essentially low, below 1%, as is also that of nitrogen. The available phosphate is generally low and because of insufficient leaching potassium content is high.

Two agricultural areas of Saudi Arabia are used as examples since there is some available information, although the country has many agricultural areas with different soil types already surveyed or under survey. These two areas are Qatif, which is situated on the coast of the Arabian Gulf, and Al-Hasa which is about 160 km from Qatif in a south-west direction.

10.2. Climate

Data recorded during the years 1964-69 in Qatif Experimental Farm showed that:

- temperature ranged from 10°C in winter to 43°C in summer as mean monthly data
- monthly recorded rainfall data ranged from 1.9 mm in 1966 to 122 mm in 1968.

10.3. Soils

In a soil profile at Qatif the parent materials of the soils show a great variation resulting in rather large differences in the soil profile. Influencing phenomena are (Soil Survey 1963):

- limestone and marl formation and their erosion products
- aeolian desert sand
- tidal sediments of the sea

The most important aspect of the soil profile in the area is the occurrence of a calcareous hardpan, a cemented, hardened and less permeable layer. Generally, this

layer exists at a depth of 50-70 cm below the soil surface. In most cases, the thickness of this layer is about 40-50 cm, although layers of 80-100 cm are no exception.

The consequences of the occurrence of this hardpan were thought to be that the root development of crops might seriously be hampered and that the drainage profile might be restricted owing to its limited permeability.

When these soils were reclaimed, the hardpan gradually dissolved and its detrimental effect was strongly reduced within a two year period. The material overlying the calcareous hardpan is generally sand, but in places layers of even, silty clay and all possible transitions are found. The material below the hardpan varies to a great extent. Coarse-textured materials, however, exists in all profiles.

The variations occur at very short mutual distances and at different depths, consequently the area can be considered heterogeneous with very light-textured soils.

For illustrative purposes, a review is given hereunder of a typical soil profile as far as texture is concerned:

| | |
|-------------|--------------------|
| 0 - 15 cm | loamy sand |
| 15 - 40 cm | medium coarse sand |
| 40 - 60 cm | loam |
| 60 - 85 cm | loamy sand |
| 85 - 120 cm | coarse sand |

Below the calcareous hardpan, an impervious layer is found at a depth of 2 metres in places.

10.4. Soil Salinity

From observations made during the soil survey (ILACO 1963) it was established that the soils were strongly saline. The content of easy soluble salts ranged from 0.5-4%. Determination of the electrical conductivity of the saturated extract before leaching resulted in average values of 23.5 mmhos/cm at 25°C at a depth of 0.15 cm and 17.0 mmhos/cm at a depth of 0.50 m. Next to the easily soluble salts there existed a considerable amount of less soluble salts, mainly consisting of gypsum to a minor degree of CaCO₃. The content of gypsum and CaCO₃ together, as found in the sample analysed, ranged from 30-40% of the total soil mass.

The Soil Survey also showed that pH values were found to range from 7.2 to 8.2.

10.5. Irrigation and Drainage

The area is supplied with water from artesian wells. There is a drainage system constructed by the Government throughout the Qatif area.

10.6. Quality of Irrigation Water

The analytical data available on the water to be used for irrigation revealed that most artesian wells supplied water with EC values of 2.8-4 mmhos/cm. This quality class of water is not suitable under ordinary conditions, but may be under special circumstances, such as permeable soils or adequate drainage. Water must be applied in excess to provide considerable leaching and very salt tolerant crops should be selected.

Data of the chemical properties of the irrigation water are given in the following table (Analysis by ARAMCO)

| ION | PFM |
|------------------|----------------------------------|
| Na | 344 |
| K | 20 |
| Ca | 195 |
| Mg | 76 |
| SO ₄ | 451 |
| Cl | 625 |
| HCO ₃ | 195 |
| Total | 1 886 = approx EC = 2.9 mmhos/cm |
| SAR approx = 6 | |

10.7. Land Reclamation

Soil reclamation is by leaching in order to minimize to a level suitable for plant growth the soil total content of soluble salts. The following technique is used.

The first water application is used to soften the soil, then the salt encrusted surface is broken up and pulverized; this improves the topsoil permeability and leaching. The operation was carried out with a heavy tractor-mounted cultivator with rigid, deep-digging shanks, equipped with sharp, narrow shovel points acting like a ripping plough.

The breaking up of salt crusts and hardpan, where feasible, should be repeated as many times as possible at gradually increasing depths. The use of a plough, whether disc or mouldboard for this work should be avoided since this implement turns the soil over, thus bringing to the surface again all the salts that have been washed down.

During and after these mechanical soil improvement activities, pre-sowing water applications should be given to leach out salts.

The usual procedures for full reclamation of the soil are leaching followed by growing barley, ploughing this crop under and then keeping the area under alfalfa for one season or else a heavy application of farmyard manure is given immediately after the initial leaching period.

The results obtained during the last few years have proved that the organic matter is essential in the production of vegetables in this particular soil. Moreover, the results indicate that chemical fertilizers are more efficient if they are combined with an adequate addition of farmyard manure applied prior to sowing or planting of the crop.

There exists an insignificant difference between the effect of combined and single fertilizers on the yield. Phosphate is essential for attaining high yields, whereas potassium was not, probably because an adequate quantity of this element is supplied by the irrigation water in addition to its soil content.

There are two experimental stations in the eastern province of the country, one at Qatif and the other at Al-Hasa. Qatif station concentrates its research mainly on horticulture, whereas the Al-Hasa station does research on both animal production and forage crops. Al-Hasa soils are similar to Qatif's in texture but have less salinity and CaCO_3 . The Al-Hasa area is irrigated mostly from springs that are combined in one vast irrigation system, the largest irrigation project in the country that is designed to cover 20 thousand hectares. Research on saline and calcareous soils of Al-Hasa is still in progress with the assistance of both Leicht Weiss Institute of West Germany and the University of North Wales of Great Britain.

In the Qatif station, a research programme is run mainly on vegetables, industrial crops, some fruit trees, forage crops, weed control and date palm trees. Experiments on these crops include fertilizer trials, variety selection and date of planting.

11.1. Introduction

The climate of Somalia is arid and semi-arid with two rainy seasons. The annual rainfall and distribution fluctuate from year to year, for example in the Afgoi district the annual rainfall in 1970 was about 400 mm but in 1972 it was over 800 mm.

Somalia has 10 million ha of arable land, 2 million ha of which lie in the inter riverine area. Of the cultivable land 500 000 ha are under cultivation of which 400 000 ha are dry farmed, 80 000 ha are flood irrigated and 20 000 ha are regularly irrigated.

11.2. Soils

A major portion of the Somali soils are calcareous, but the agricultural areas are not highly so. Out of 800 samples collected from widely scattered areas along the Wadi Shebelli and the Giuba Valleys, 30% contained less than 10% calcium carbonate, 31% contained from 10-20% and 39% contained from 20-30%. The pH of these samples was from 7.2 to 8.2 with 8.0 being the predominant value.

11.3. Nutrient Status

The data in the following table shows the results of maize nutrient requirement studies on calcareous soils being done at the Central Agricultural Research Station at Afgoi.

The objectives of the experiment are to determine:

- (i) which elements are deficient in the soil
- (ii) the fertilizer requirement of maize
- (iii) the response of maize to fertilizer under irrigated conditions
- (iv) the correlations between soil test and yield at the end of the experiment (which is still continuing). The average calcium carbonate of this soil is 21%.

Future experiments on this soil will include the following three main subjects: The continuation of fertility studies, Water use and Manuring.

Nutrient requirements of maize grown on calcareous soils

| GU Season: April-June 1971 | | Deir Season: October-December 1971 | |
|----------------------------|----------------------------|------------------------------------|----------------------------|
| Treatment N - P - K | Average yield 100 kg/ha | Treatment N - P - K | Average yield 100 kg/ha |
| 0 - 0 - 0 | 18.9 | 0 - 0 - 0 | 13.8 |
| 0 - 50 - 0 | 22.7 | 0 - 50 - 0 | 13.2 |
| 0 - 100 - 0 | 21.4 | 0 - 100 - 0 | 13.3 |
| 50 - 0 - 0 | 30.6 | 50 - 0 - 0 | 23.6 |
| 50 - 50 - 0 | 39.6 | 50 - 50 - 0 | 22.8 |
| 50 - 100 - 0 | 36.3 | 50 - 100 - 0 | 21.2 |
| 100 - 0 - 0 | 38.9 | 100 - 0 - 0 | 20.4 |
| 100 - 50 - 0 | 38.5 | 100 - 50 - 0 | 30.4 |
| 100 - 100 - 0 | 40.2 | 150 - 0 - 0 | 27.9 |
| 150 - 0 - 0 | 40.8 | 150 - 50 - 0 | 30.6 |
| 150 - 50 - 0 | 34.2 | 150 - 100 - 0 | 32.7 |
| 150 - 100 - 0 | 35.9 | 100 - 100 - 0 | 30.0 |

Number of replications: 4

Rotation: maize after maize

Fertilizer used: Urea and triple superphosphate in kg/ha

11.4. Salinity Research Programme on Calcareous Soils in Johar Sugar Estate

Electrical conductivity of these soils ranges from 10 - 220 mmhos/cm. Reasons for this high salinity are:

- (i) high salt content in irrigation water
- (ii) excess use of irrigation water
- (iii) lack of proper drainage.

The presence of the high content of salt in the soil causes high sodium adsorption in the soil colloids, poor permeability and a high water table.

The Johar Estate poses the main soil problem in Somalia at present and shows what will happen to other calcareous but not highly saline soils if they are farmed under similar conditions as at Johar.

Recently, the following experiment has been proposed:

| <u>Treatment</u> | <u>Gypsum</u> <u>kg/m²</u> | <u>Water</u> <u>litre/m²</u> |
|------------------|--|--|
| 1 | 0 | 120 |
| 2 | 0 | 180 |
| 3 | 0 | 240 |
| 4 | 1 | 120 |
| 5 | 1 | 180 |
| 6 | 1 | 240 |
| 7 | 2 | 120 |
| 8 | 2 | 180 |
| 9 | 2 | 240 |

Concerning drainage, deep canals are made along the plots to take away extra water.

12.1. Introduction

The Sudan is a country with vast land resources. Due to shortage of capital, the national priority in agricultural development has been directed primarily towards areas where the possibility of bringing land under cultivation was low.

The problem of land reclamation for agricultural development was never tackled seriously until recently. Reclamation projects are now being considered for two areas: the Northern Province, and areas around Khartoum, which together amount to about 200 thousand ha (500 000 feddans). The need to reclaim soils in the Northern Province was dictated mainly by the favourable conditions for the production of horticultural crops. Initiation of reclamation projects in lands around Khartoum was justified by the high demand for horticultural, dairy and poultry products.

12.2. Calcareous Soils in the Sudan

Calcareous sediments in the form of limestone as soil parent material do not exist in the Sudan. The calcareous nature of the soils is a result of the precipitation of CaCO_3 under arid and semi-arid climatic conditions. Calcareous soils with diagnostic calcic horizons as defined in the 7th approximation (USDA System) have not so far been identified. The soils are classified as calcareous or non-calcareous on the basis of the presence or absence of CaCO_3 (field acid test) regardless of quantity or form.

12.3. Geographical Pattern of CaCO_3 Distribution

Under the arid conditions of Northern Sudan (rainfall less than 400 mm), CaCO_3 exists in a finely divided form incorporated with the mineral soil particles giving a calcareous matrix, together with soft powdery aggregates and hard concretions. Soils with a non-calcareous matrix to a depth of 150 cm, but with various forms of CaCO_3 concretions, occur in areas of 650 mm of rain and above.

In the dry region, the calcareous characteristic of the soil as described above is always associated with high soluble salts and gypsum deposits.

12.4. Levels of CaCO_3 Content

Calcium carbonate forms larger than 2 mm diameter in size are sieved off. CaCO_3 determination is made on the fine earth of less than 2 mm diameter. The content of such incorporated CaCO_3 , in general, ranges between 3 and 13%. In most of the agriculturally productive land, the CaCO_3 content within 600 cm is above 5%.

The table below gives some data of two profiles from Khartoum area.

| Profile No. | Depth cm | pH paste | % CaCO ₃ | Ec se | Non calcareous soil fractions-% | | | | ESP |
|-------------|----------|----------|---------------------|-------|---------------------------------|------|------|------|------|
| | | | | | C.S. | F.S. | Silt | Clay | |
| 1. | 0 - 10 | 8.4 | 10.6 | 1.1 | 31 | 21 | 10 | 27 | 27.0 |
| | 10 - 35 | 8.5 | 11.1 | 2.4 | 26 | 18 | 12 | 32 | 50.0 |
| | 35 - 55 | 8.3 | 10.9 | 6.7 | 22 | 17 | 14 | 36 | 50.0 |
| | 55 - 85 | 8.6 | 9.6 | 3.4 | 22 | 19 | 14 | 35 | 60.0 |
| | 85 - 135 | 8.7 | 10.1 | 2.9 | 23 | 26 | 14 | 26 | 61.1 |
| 2. | 0 - 35 | 8.6 | 7.0 | 13.4 | 19 | 17 | 18 | 39 | 45 |
| | 35 - 60 | 8.4 | 3.9 | 17.0 | 20 | 17 | 18 | 41 | 46 |
| | 60 - 90 | 8.8 | 4.4 | 12.6 | 19 | 17 | 18 | 42 | 44 |
| | 90 - 130 | 9.2 | 6.2 | 4.3 | 10 | 21 | 26 | 36 | 63 |

The data show that though the CaCO₃ content is around 10% in profile No. 1, yet the soil is adversely affected by the high content of sodium expressed in ESP.

Profile No. 2 shows a moderate CaCO₃ content of about 5%, and high Ec and ESP.

Both soils are more adversely affected by the presence of soluble salts and exchangeable sodium rather than by the presence of CaCO₃ which is mostly in an inactive form.

At present soil calcareousness does not seem to be a problem in the Sudan. Reactivation of the CaCO₃ under environmental conditions is needed to reduce the effect of soluble and exchangeable sodium cations. The main limitations of soils affected by calcareous characteristics are fine textures, slow permeability, associated with high salinity and sodicity.

V. SUPPLEMENTARY PAPERS

V.1. PRELIMINARY RESULTS OF LYSIMETER STUDIES ON THE DYNAMICS OF CALCIUM IN THE IRRIGATED CALCAREOUS SOILS OF SOUTH LEBANON

by

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1.1. Introduction

The concept of active calcium carbonate generally used to define the quantity of CaCO_3 which can be mobile in the soil, allows the taking into account of neither the calcium concentration in the soil solution (therefore the amount of calcium absorbable by the plant roots at a given moment), nor the movements to which this calcium can be subjected either by drainage or by being precipitated through heavy evaporation.

In a highly calcareous soil, the concentration of calcium in the liquid phase depends little on exchangeable calcium of an absorbant complex. The principal source is the carbonate of calcium existing in the solid state (mainly the CaCO_3 called 'active') and the principal factor of solubility is the partial pressure of the carbon dioxide contained in the soil's atmosphere.

In this report are presented the experimental results concerning the calcium content of water which has passed through calcareous soil subjected to various treatments and these results are discussed in relation to the theoretical concentration of a saturated calcium solution.

The object of such work is to define the nature of the different phases in the calcareous environment in which the vegetation grows during the course of the year and to study some elements leading to a knowledge of the evolution of this environment under the effect of intensive irrigation and the application of fertilizers.

1.2. Experimental Material

The material which served to support our efforts came from the experimental station of the National Litani Office at Lebaa near Saïda. This material had been previously set in the soil enabling it to be linked with one of the inventory series at the time of the pedological study of the joint FAO-NARI(IRAL) project in the Daoudiyé trials. Its chief characteristics are: uniformly deep brown colour, differentiation of weakly defined horizons, depth varying between 50 and 80 cm, percentage of coarse material (before

clearing of stones) of about 15%; the main analytical data are the following:

| | |
|-----------------------------------|--------|
| content of total CaCO_3 | = 50% |
| content of active CaCO_3 | = 22% |
| organic matter | = 1.5% |
| clay | = 48% |
| fine silt | = 33% |

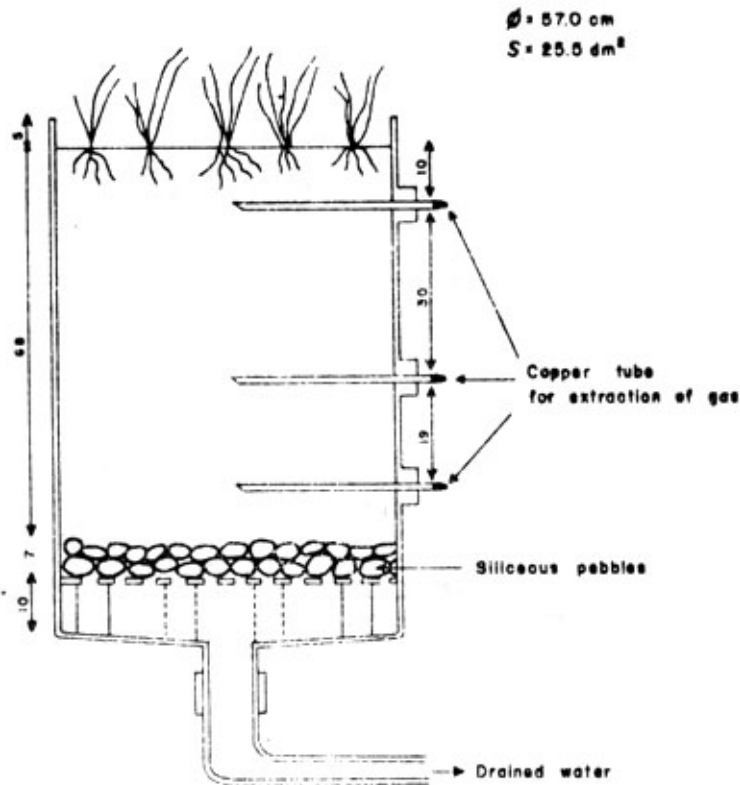
The clay fraction is composed of 21.8% calcium carbonate and 6.05% magnesium carbonate. In the rest (that is 72.2%) there are found mainly clay minerals of the type 2/1 (montmorillonite), a little kaolinite and some iron.

The distribution of calcium carbonate has also been studied and of magnesium among the different granular fractions: 53% calcium carbonate was found in the silt fraction, against only 24% in the clay fraction and 23% in the sandy fraction. It follows that the active CaCO_3 comes more from the calcareous grains contained in the fine silt than from those contained in the clay. The silt seems to play an important role as well with regard to the hydraulic properties of the soil.

1.3. Experimental Apparatus

This consists of a battery of six lysimeters: small barrels of 200 litre capacity pierced underneath to allow the collection of drained water (Figure 1). In addition three copper tubes were introduced laterally at depths of 10, 40 and about 60 cm for the removal and the titration of the carbonic gas in the soil atmosphere.

Figure -1 - Cross section of a Lysimeter



The following treatments were carried out on each lysimeter:

| Lysimeters No. | Pebbles | | Irrigation | | Minimum Fertilizer | |
|-------------------|---------|---------|------------|---------|--------------------|---------|
| | with | without | with | without | with | without |
| 1 | + | | + | | | + |
| 2 | | + | + | | | + |
| 3 | + | | + | | + | |
| 4 | | + | + | | + | |
| 5 | | + | | + | | + |
| 6 | + | | | + | | + |

Fescue grass (*Festuca arundinacea*) was sown in June 1970 on lysimeters 1, 2, 3 and 4, and lysimeters 5 and 6 were kept permanently without any vegetative cover.

The four irrigated lysimeters each received considerable and identical quantities of water: 1 400 mm in 1970 and 1 600 mm in 1971. The water came from the Karaoun dam and contained very little chlorine and sodium; on the other hand it was always super-saturated with calcium carbonate (between 51 and 65 mg/l of calcium).

Two applications of fertilizers were made on lysimeters 3 and 4, one in May 1970 (per hectare: ammonium nitrate 400 kg, triple superphosphate 2 000 kg and potassium chlorate 480 kg) and the other in November of the same year (ammonium nitrate 600 kg).

The amounts of water drained from each lysimeter were measured daily. Average samples of this water were taken and analysed about once a month. The CO₂ content of the soil atmosphere was determined every month from December 1970 onward with the Drager gas detection technique.

1.4. Results obtained in 1970 and 1971

a) CO₂ content in the atmosphere of the lysimeters in 1971 (Figure 2)

A first fact is recognized which is valid for all the lysimeters except sometimes for No. 1: the CO₂ content increased with depth whatever the season.

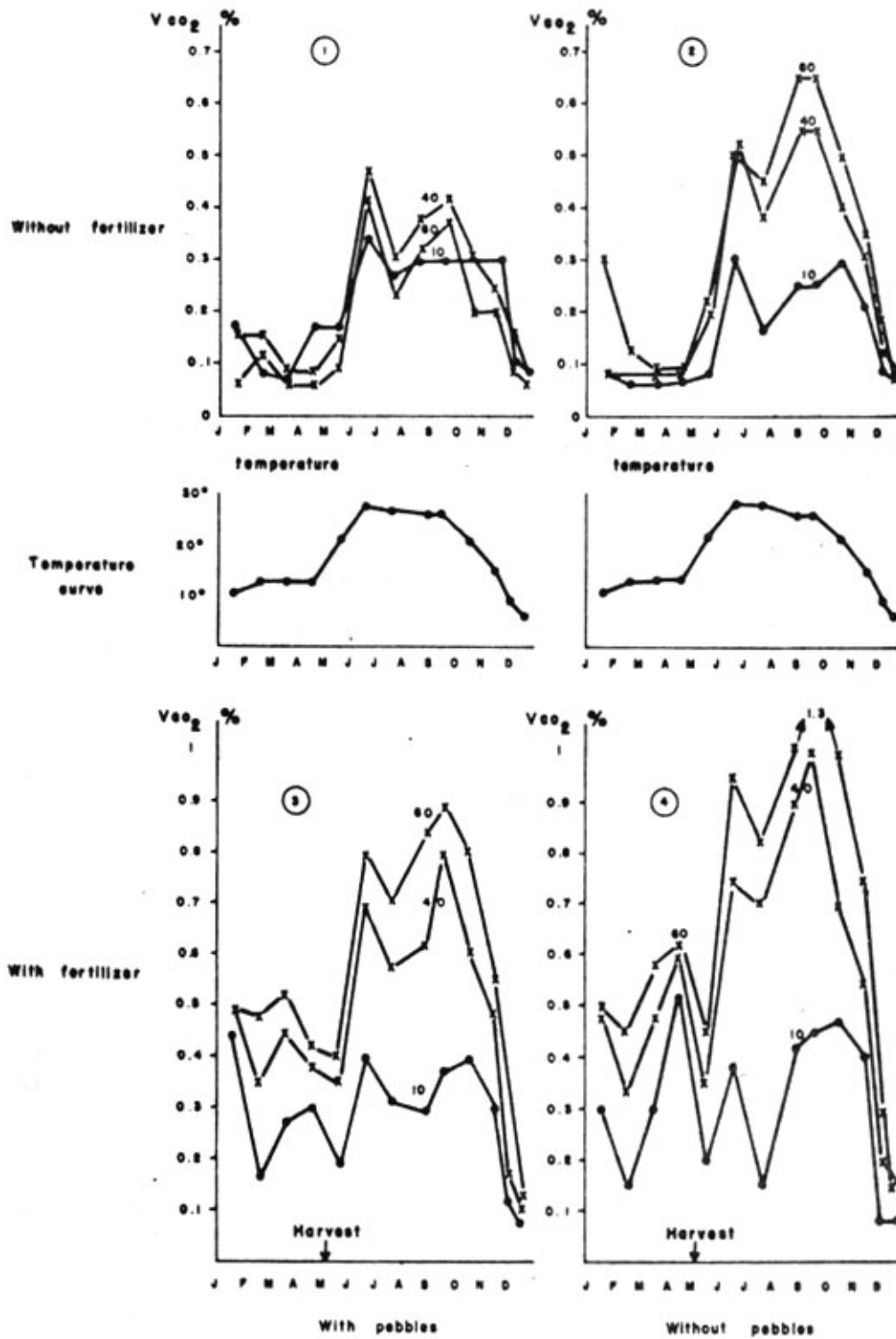
In the two non-irrigated trials (5 and 6), the CO₂ content was 0.03% from June to November. Then it increased slowly until in the month of April it reached a maximum which was no greater than 0.08% in 1971 but which rose to 0.35% at 60 cm in 1972.

In the four irrigated lysimeters, on the other hand, the quantity of CO₂ was slightly greater between June and November than between November and May. The curves had summarily the same form as the curve for the mean monthly temperatures. So the sharp decline in the CO₂ content observed between the 17 November and 7 December corresponds to a sudden coldness in the climate (from 20°C to 6°C).

Two maximums in the CO₂ content appeared at the same time in the 4 lysimeters, one in June and the other more noticeable in September.

The minimums came on the one hand in February-March and on the other in December. There was also a reduction, temporary but none the less obvious, in July.

Figure 2 Content in CO₂ in the atmosphere of the lysimeters at 10 cm 40 cm 60 cm



It could be judged therefore that the application of fertilizers had the effect of increasing the CO₂ content, by stimulating bacterial activity and respiration of the roots.

Moreover, it seems that in lysimeters 3 and 4 the release of CO₂ linked with the biological activity is felt from the end of March. On the contrary, the cutting carried out in May would cause better diffusion of the carbonic gas in the outside atmosphere, therefore a lowering of the CO₂ content in lysimeters 3 and 4 in May and June.

Finally it should be noted that the May to September CO₂ contents at 40 and 60 cm are always higher in lysimeters 2 and 4 containing soil without pebbles, than in lysimeters 1 and 3 where the stones have not been removed.

b) Concentration of calcium in drainage water

Lysimeters with non irrigated trials

The only data obtained during the winter of 1970-1971 having proved insufficient we wished to complete them with data gathered during the course of the winter of 1971-1972. At the time of the first rain it was ascertained that the drained water and above all that which came from lysimeter 6 was turbid and very rich in solid matter in suspension. At the same time the strength of calcium was relatively high (50 and 70 mg/l). Then very rapidly the particles in suspension disappeared while the calcium concentrations were stable until February (60 to 70 mg/l).

In March there was a fall in the calcium concentration, the minimum reached at the end of March was between 35 and 50 mg/l.

Lastly, in April at the time when the contents of CO₂ are highest, the calcium concentrations again became identical to those observed in January-February. Thus in uncultivated and non irrigated calcareous soils the leaching of CaCO₃ during the first rains should be considered in relation to the drying that the earth has undergone during the summer and with the settling which has resulted.

This is the mechanism of pelicular alteration to calcareous stones which happens in this medium which is porous, inflated and poor in organic matter. The calcium carbonate goes into suspension rather than dissolves in the water.

In April, on the contrary, it is the presence of carbonic gas which causes a dissolution of the "carbonate reserve" which was extant in the soil.

Irrigated lysimeters (Figures 3 and 4)

The influence of irrigation and the application of fertilizers on the concentration of calcium in the drainage water is illustrated by the curves in Figures 3 and 4.

No matter what the material (earth with or without pebbles) and whether fertilizer has or has not been added, periodical variations exist in the calcium concentration. These differences are based in the first estimate in the same way as the variations in the CO₂ content of the atmosphere.

Although the minimums were observed at the same time (April) and had appreciably the same value of nearly 10 mg/l for the two years, in contrast there was a clear enough difference between the maximums of 1970 and those of 1971. In 1970 the maximums in lysimeters 1 and 2 were observed in June (87 and 100 mg/l) and September-October (78 and 94 mg/l). In 1971 in the same lysimeters the maximums were respectively no more than 60 to 65 mg/l and 70 to 75 mg/l during a period stretching from August to December. The measurements taken in the first seven months of 1972 confirm that there is from one year

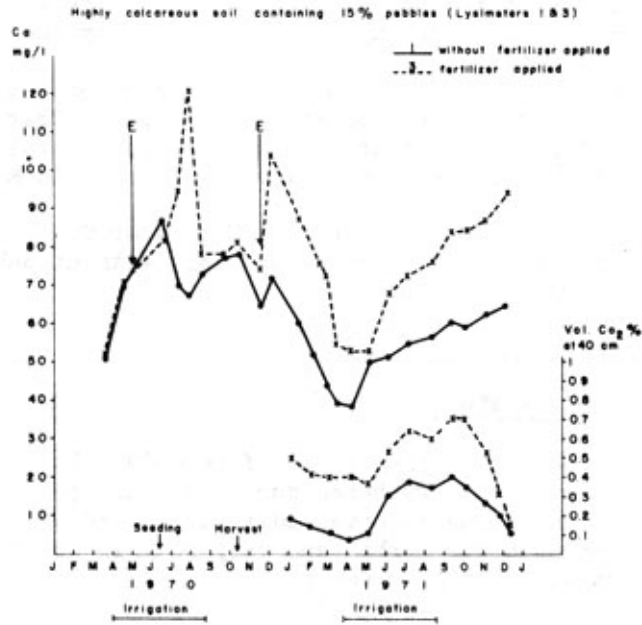


Figure 3 Concentration of calcium in the drained water
Average content of CO₂ in the atmosphere of the Lysimeters (at 40 cm)

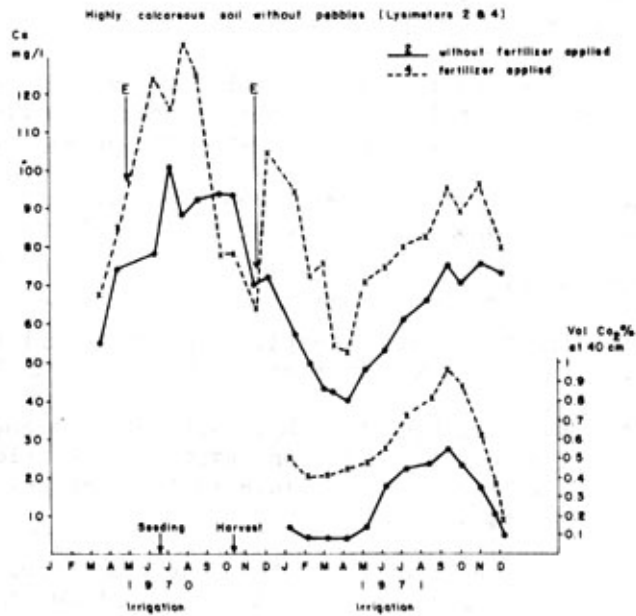
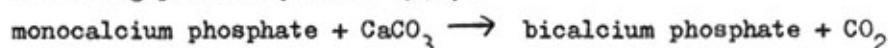


Figure 4 Concentration of calcium in the drained water
Average content of CO₂ in the atmosphere of the Lysimeters (at 40 cm)

to another a progressive decrease in the concentration of calcium in the drained water especially during the irrigation period. It was also noted that the first rain in November-December seemed to elicit a more intense but ephemeral enough dissolution of the calcium carbonate rather as in the test lysimeters, although this period corresponds to a sharp decrease in the CO_2 content.

In May 1970 fertilizer application to Nos. 3 and 4 caused a strong rise in the concentration of calcium in the drained water in July-August. The same thing happened, although not so severely, after the second application of nitrate in December 1970. This influence from the fertilizers was still to be seen in 1971, but it was much less obvious. The absence of data concerning CO_2 in 1970 allowed us to make only two observations regarding the action of the fertilizers. These occurred in two ways:

- indirectly by stimulating bacterial activity and root growth. The resultant carbonic gas caused intense solubility of the calcium carbonate.
- directly with regard to the monocalcium phosphate (triple super-phosphate). In effect this reacted rapidly on the calcium carbonate in the following pattern (ARVIEU 1972):



The carbonic gas which was released reacted in its turn with the lime and caused its dissolution (peak in June-July 1970).

In a second stage the bicalcium phosphate reacted slowly with calcium carbonate to create octocalcium phosphate at first and then apatite calcium, both of them insoluble therefore unavailable to plants. During the course of this second stage, which was slower than the first, there was also a release of CO_2 . According to ARVIEU the two stages happen far more quickly and with a far greater speed when the temperature is higher and the quantity of CaCO_3 is greater.

At the limit the two stages occur simultaneously, the bicalcium phosphate reacting on the calcium carbonate at the same time as it forms.

c) Comparison between the concentrations of calcium measured and the theoretic concentrations of saturated calcium (Figures 5 and 6)

The concentration of theoretic calcium in a saturated solution in the presence of pure calcite is linked with the partial pressure of CO_2 by the following relation:

$$\log [\text{Ca}^{++}] = 0.33 \log \text{PCO}_2 + b \quad (1)$$

the value of b varies in terms of the temperature according to the following relation established by T. Stchouskoy-Muxart

$$\log b = -0.055 \log t + 0.4605$$

if it is admitted that the atmospheric pressure is constant and equal to 1 atmosphere, the following is given:

$$\text{PCO}_2 = \frac{\text{VCO}_2}{100}$$

VCO_2 being the volume of CO_2 in the soil atmosphere expressed in percent; the equation (1) becomes:

$$\log [\text{Ca}^{++}] = 0.33 \log \text{VCO}_2 + (b - 0.66)$$

to simplify the calculations the variable $\log 1000\text{VCO}_2$ has been used in the place of $\log \text{VCO}_2$. Therefore the relation obtained is:

$$\log [\text{Ca}^{++}] = 0.33 \log \text{VCO}_2 + b - 1.32 \quad (2)$$

the right side terms in equation (2) for different temperatures have been shown in Figure 5.

Figure 5 Concentration of calcium in the drained water
in relation to the CO₂ content at 80 cm

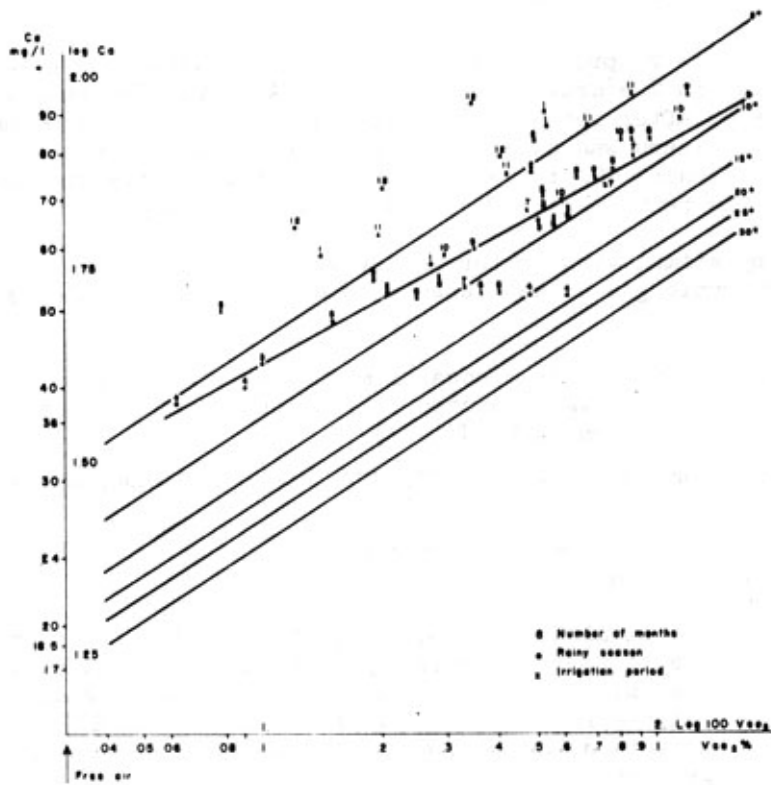
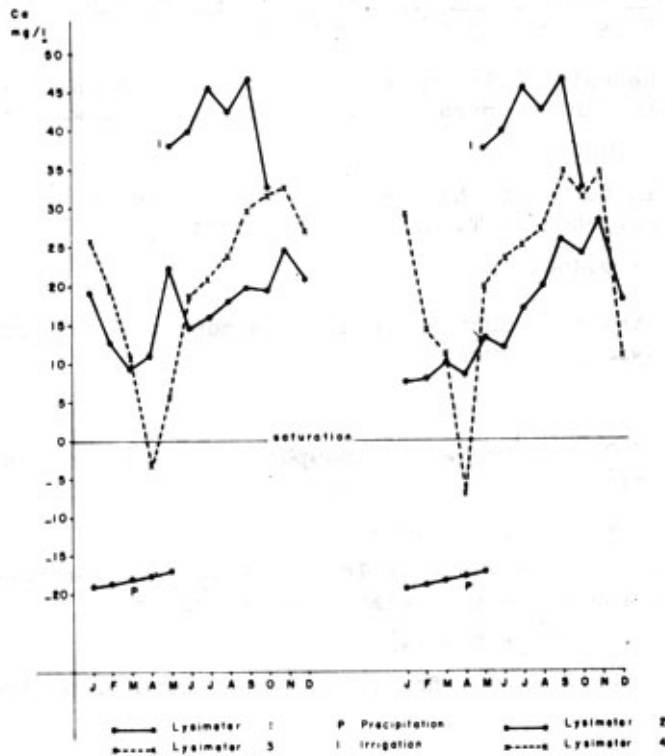


Figure 6 Excess or deficit of calcium in the water
in relation to the saturation



One can therefore, knowing t and VCO_2 calculate $[Ca^{++}] = S$: concentration of theoretical calcium from the water of the saturated soil.

The difference C-S between the concentration measured and the theoretical concentration, for the same content in CO_2 of the atmosphere and for the same temperature, allows the estimation of the excess or deficit of calcium in the water having passed through the lysimeters and the comparison of this to the values obtained for the rain-water and for the irrigation water. All these values collected in 1971 are given in Figure 6. It can be calculated that in the four irrigated lysimeters the values of C-S were at a minimum in April and at a maximum in November. The drained water from lysimeters 1 and 2 was constantly supersaturated with calcium whilst in lysimeters 3 and 4, which had received fertilizers in 1970, this water showed in April a loss of calcium in relation to the saturation; on the contrary from June to December the excess of calcium was higher than in the water coming from lysimeters 1 and 2. It seems, therefore that nearly always the percolation water is supersaturated with calcium; in other words, only part of the calcium was found in solution in the form of bicarbonate of calcium whilst the other part was in the form of very fine calcareous particles in suspension in the water. It is moreover the same thing for the water used for irrigation which is, as shown by the I curves, extremely supersaturated with regard to an equilibrium content of calcium in natural water. From this fact irrigation water has a very different action on calcareous soil to that exercised by rain water which has a stronger dissolving action.

One can interpret the curves in Figure 6 in the following way. In the autumn the soil encloses a high reserve "of easily soluble calcium carbonate" (calcium carbonate carried by the irrigation water or coming from the alteration of the pre-existing $CaCO_3$). Rain water carries away during the course of its passage through the soil not only calcium bicarbonate but also some very fine particles in suspension. Gradually as the winter passes, the reserve of $CaCO_3$ diminishes and the quantities of calcium carried away show a noticeable reduction. In lysimeters 3 and 4, the content in CO_2 being higher, the reserve of "easily soluble calcium carbonate" is more rapidly reduced so that in April the drained water is under-saturated. From May onwards there is not only a carrying away of calcium but also a depositing in the soil of a part of the calcium contained in the irrigation water. The difference between the saturation curves of the irrigation water and those of the drained water represented on Figure 6 illustrates the quantities of calcium which have remained in the soil. One can estimate that these quantities are higher in lysimeters 1 and 2 than in lysimeters 3 and 4.

d) Deposits and losses of calcium between June 1970 and October 1971

Table 1

Additions (+) and losses (-) of the quantity of calcium in the irrigated and non irrigated lysimeters in 1970 and 1971

| Lys. No. | from 1. 6.70 to 10.11.70 | from 11.11.70 to 19. 4.71 | from 20. 4.71 to 19.10.71 | Total |
|----------|--------------------------|---------------------------|---------------------------|--------|
| 1 | + 14.7 | - 8.9 | + 17.0 | + 22.8 |
| 2 | + 13.8 | - 9.3 | + 14.8 | + 19.3 |
| 3 | + 23.0 | - 14.4 | + 15.4 | + 24.0 |
| 4 | + 21.6 | - 15.0 | + 14.0 | + 20.6 |
| 5 | - - - | - 9.7 | - - - | - 9.7 |
| 6 | - - - | - 8.5 | - - - | - 8.5 |

The figures in the preceding table represent the difference between the quantities of calcium supplied (with the water and with the mineral fertilizers) and the quantities carried away by lixiviation and in the harvest.

During the winter of 1970-71 lysimeters 1, 2, 5 and 6 released into the drained water about the same quantity of calcium (9 to 11 g), while Nos. 3 and 4 lost a lot more (15 g about).

During the two summers, lysimeters 1, 2, 3 and 4 were watered with the following significant quantities: 355 and 426 litres. Owing to the intense evapotranspiration the volume of drained water only represents about a third of the irrigation water. For this reason and also because the drained water is clearly less saturated than the irrigation water, the quantities of calcium lost are hardly significant (13 to 17 g) when considered against the quantities of calcium added (45 g). Irrigation for lysimeters 1 and 2 definitely indicates an increase in calcium of 31.7 and 28.6 g and for lysimeters 3 and 4 an increase of 28.6 and 26.2 g. But to these last two figures should be added also 9.4 g of calcium coming from the phosphate fertilizer in 1970 (the triple superphosphate used included 18.7% Ca). In relation to the calcium phosphate ammonium phosphate would introduce the double advantage of not increasing the calcium content of the soil on one side and on the other of lasting much longer in an assimilable form (Arvieu 1972).

Finally the overall balance (last column in the table) demonstrates, and it could not be clearer, that the irrigation of calcareous soils with water supersaturated with calcium bicarbonate, causes an enrichment of calcium which is not compensated by the lixiviation in winter under the influence of rain water.

1.5. Conclusion

It appears from the preliminary studies undertaken in the lysimeters that the carbonic gas contained in the soil body, the content of which varies considerably during the course of the year as a result of the processes undergone by the soil, is an important factor in the solubility or precipitation of calcium. But this is not the only factor which interferes with the dynamics of the calcium. Account must be taken of the existence of very fine calcareous particles in suspension in the gravitational water.

From the practical point of view it confirms that irrigation of calcareous soils with water containing high percentages of calcium carbonate shows a clear enough increase in the quantity of CaCO_3 in the soil, an increase which in the long term could have a harmful effect on the plants. Furthermore, the use of calcium phosphate as a fertilizer must be reconsidered in the light of its contribution to the increase in calcium and the rapidity with which this fertilizer is rendered unavailable in a calcareous soil.

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2.1. Definition

Contrary to saline and alkali soils, there is no accepted definition for calcareous soils. The available definitions are thought to be inadequate when plant growth and production are considered. Since several phenomena such as micronutrient deficiencies lime induced chlorosis and phosphate fixation are associated with the presence of certain levels of CaCO_3 in soil, they could be used as criteria for defining calcareous soils. In a study by Hilal et al. (4) on a chemical and biological approach toward the definition of calcareous soils, phosphorus retention was investigated as a criterion.

A set of soil mixtures, ranging in CaCO_3 content from 0 to 96%, was prepared and used in a column study to determine the level at which the CaCO_3 fraction becomes a dominant factor controlling P^{32} movement and distribution.

Detection of P^{32} in the displaced soil columns' solutions revealed that the downward movement of P^{32} in fine sand columns was much higher than in loam columns and was very low in oolitic sand. Increasing the percentage of oolitic sand in the soil mixture from 1 to 10% caused a sharp drop in P^{32} recovery with the displaced soil solutions. Any increase in CaCO_3 content from 10 to 96% did not show any further drop in P^{32} movement. A picture that is thought to be similar to that of solubility and saturation in simple solutions. Application of CaCO_3 in the clay fraction also brought out the saturation effect on P^{32} movement at 2% only.

The amount of P^{32} removed with the soil solutions was generally low compared to that retained in the soil columns. Counting the activity of P^{32} in soil columns' sections, after five displacements, indicated that P^{32} movement from the top soil increased by increasing CaCO_3 from 1 and 2% to 6%. The amount of P^{32} removed from the top soil was however retained in lower sections. A very sharp decrease in the amount of P^{32} migrating from the top soil was observed when CaCO_3 content was raised from 8% to 10%. More than 70% of added P^{32} was retained in the top section of the 10% column, compared to less than 10% retained in top sections of columns containing lower levels of CaCO_3 . Increasing CaCO_3 above this level was far less effective. A similar picture was shown when the CaCO_3 material used was in a clay size fraction. However the sharp increase in phosphate retention in the top section took place at 8% CaCO_3 rather than at 10%.

The results of this study indicate that a proposal to consider 8 to 10% CaCO_3 as a limit for defining calcareous soils is worth more consideration.

As a follow up, a pot culture experiment was conducted to determine as a criterion for the definition of calcareous soils the CaCO_3 percentage at which it exerts its drastic effect on plant growth and P^{32} and Fe uptake. Soil mixtures were prepared by mixing different calculated amounts of Nile loam, fine sand and fine oolitic sand to give soils 1, 2, 4, 6, 8, 10, 20, 30, 40 and 50% CaCO_3 . The mixtures were so prepared that their clay contents were equal and had the same texture. Corn plants were selected for this study.

The results of plant growth and P^{32} and Fe uptake support each other and clearly indicate that when $CaCO_3$ reaches 8% of the soil components, it controls the biological and chemical characteristics of the soil. A conclusion was drawn that 8% $CaCO_3$ could be the margin at which the soil can be considered calcareous.

2.2. Nutrient status

Research carried out concerning the status, behaviour and availability of nutrients in the calcareous soils of Egypt revealed the following:

a) Phosphorus

Laboratory, pot and field experiments by El-Damaty *et al.* (1) showed that calcium carbonate is the main compound limiting the phosphate availability to plants, the effect being dependent on the particle size of carbonates. Retention of phosphate opposite to its release was proved to be favoured by the existence of calcium carbonate particularly if the latter is in fine particles.

It may be worth mentioning that the so-called "P-maximum release" obtained from certain leaching techniques, was found to be a good estimate for phosphate availability to plants. The study revealed that calcareous soils are, sometimes, higher in their supplying power than those of a silicate nature possibly due to the energy of a desorption on the surfaces of soil particles.

Experiments also indicated that certain processes seemed to be encouraging for phosphate retention in calcareous soils. Relatively high temperature along with successive wetting and drying cycles of soil proved to favour the depressing of the phosphorus availability. Retention of phosphate was found to be increased with incubation as well as when soil was subjected to interchanging cycles of wetting and drying.

b) Potassium

Studies by Metwally and El-Damaty (5) showed that values obtained of the water soluble, exchangeable, and non-exchangeable K and total K were comparatively lower than those of the alluvial soils. The last three forms correlated significantly with the clay content and negatively with the $CaCO_3$ per cent. The non-exchangeable form of K, determined by heating at $500^\circ C$ for two hours and subsequent extraction with 1.0N $NH_4 OAc$, was found to give the highest correlation with the potassium uptake in a continuous experiment.

The supplying power of the calcareous soils was lower than that of the alluvial soils, even when their content of non-exchangeable K was approximately similar. This was thought to be due to the high Ca and Mg content of the calcareous soils, since the activity ratio of K ($a_K / \sqrt{a_{Ca}}$) was found to control the uptake of K by maize and soybean from sand cultures, more than the K activity. Increasing the Mg concentration from 1×10^{-5} mol/l to 5×10^{-5} mol/l largely decreased K uptake at constant K-activity and K-activity ratio.

Potassium bonding energy as estimated from Langmuir adsorption isotherms and K-fixation were found to be much lower in calcareous soils than in alluvial soils.

c) Iron

The total amount of iron was found by Elgala (2) to be about 5.5×10^3 ppm with only about 13 ppm as available iron. With respect to the behaviour of added iron compounds, results show that the application of iron sulphate did not cause a pronounced change in the amount of water, and NH_4OAC soluble iron but that the Fe EDDHA addition resulted in a significant increase in the amount of water soluble iron.

A positive response in plant growth, dry matter and protein nitrogen content was obtained when iron was applied in the form of Fe EDDHA to the soil or as a foliage spray on corn plants grown in a calcareous soil at Burg El-Arab, west of Alexandria. The ineffective use of iron sulphate as compared with the iron chelate was found and was related to the rapid oxidation or precipitation of Fe SO_4 .

Plants grown on a calcareous soil showed chlorotic symptoms and severity of chlorosis was related to the level of phosphorus fertilizers and soil moisture content. The percentage of "active iron" decreased by increasing phosphorus level and soil moisture content.

d) Manganese

The total amount of Mn in Egyptian calcareous soils was found by Elgala (2) to vary between 125 and 220 ppm while the available amount ranges from 45 to 100 ppm. Metwally and El Damaty (5) using the isotopic exchange technique showed that the equilibrium Mn in calcareous soils includes, beside the water soluble and the exchangeable Mn, the chelated Mn as extracted by 0.1 N pyrophosphate zinc sulphate in 1N NH_4OAC for two hours and the portion of easily reducible Mn extracted by 0.025% hydroquinon. The conventional extractant, namely 0.2% H.Q. used to extract what was agreed upon as easily reducible Mn, extracted non-equilibrium Mn even after 30 minutes of extraction. Manganese extracted by 0.025% H.Q. was found to be mainly the trivalent form as extracted by 0.1 M pyrophosphate (Na-pyrophosphate).

Manganese extracted by both 0.1M Na pyrophosphate and 0.025% H.Q. gave the highest significant correlation with the Mn uptake by soybean. The two extractants proved to be more reliable than other extractants of H.Q. of higher concentrations which extracted non-equilibrium Mn and resulted in lower correlation coefficients with the Mn uptake. They were also superior to the other extractants used, i.e. 0.1M H_3PO_3 , 0.05M Na-EDTA, NaOAc of pH 5.5, as far as estimating plant available Mn was concerned.

When Mn was added to calcareous soils under normal moisture conditions, chemical and biological oxidation proceeded much more rapidly than under waterlogging conditions. The Mn^{++} added undergoes rapid oxidation and may be precipitated as hydrated $\text{Mn}(\text{OH})_2$ or MnCO_3 which is immediately oxidised. These hydrated freshly precipitated oxides are considered to constitute part of the equilibrium Mn, but they become inert, more ordered and less active upon dehydration and therefore transformed to non-equilibrium manganese.

The calcareous soils due to their lower adsorption capacity and microbial activity can maintain higher Mn^{++} concentration in the active form for a longer period than alluvial soils when it is added to the soil.

e) Zinc

The total amount of Zn in Egyptian calcareous soils as determined by Elgala (2) varies between 18 and 28 ppm, while the available amount ranges from 1.1 to 1.8 ppm.

Barley plants showed a higher content of Zn when Zn fertilizers were applied to various calcareous soils containing from 20% to 70% CaCO₃, which indicates the deficiency of Zn in such soils. However, the chelate form of Zn EDDHA was more highly efficient than the inorganic form in supplying available Zn. There was a noticed decrease in plant uptake of Zn as a function of increasing phosphorus or CaCO₃ content in the soil.

Metwally and El Damaty (5) found that when the chemically available zinc extracted by 1.0N, 0.5N, 0.1N HCl, 2.0N MgCl₂, Na₂-EDTA, and dithiozon, was correlated with the plant uptake of zinc, only dithiozon and Na₂-EDTA gave significant correlation.

The eight calcareous soils used responded to zinc fertilization at a rate of 3.0 mg/kg soil, and were believed to be zinc deficient compared to the alluvial soil used which gave no response to such fertilization.

f) Boron

Metwally and El Damaty (5) in their study of boron adsorption by calcareous soils found that the adsorption capacity of calcareous soils was much lower than alluvial soils owing to their lower content of amorphous oxides that are the main soil constituents contributing to boron adsorption and fixation.

2.3. Improvement of some physical properties

The effect of cropping with alfalfa for different periods on the organic matter content and some physical properties of the calcareous soils in the northern region of Tahrir Province was studied by El Maghrabi et al. (3). The results are given in the following table.

| Sampling date | Cropping period (month) | Organic matter % | Bulk density (g/cm ³) | Porosity % | Hydraulic conductivity (cm/hour) | Infiltration rate (cm/hour) | Moisture equivalent % |
|---------------|-------------------------|------------------|-----------------------------------|------------|----------------------------------|-----------------------------|-----------------------|
| 22.5.1971 | 0 | 0.15 | 1.74 | 36.9 | - | 1.45 | 14.9 |
| | 13 | 0.26 | 1.64 | 39.0 | - | 2.41 | 18.0 |
| | 18 | 0.30 | 1.55 | 42.0 | - | 2.95 | 18.3 |
| | 31 | 0.39 | 1.44 | 46.0 | - | 5.83 | 20.9 |
| 22.5.1972 | 0 | 0.16 | 1.75 | 37.0 | 0.24 | 1.36 | - |
| | 25 | 0.34 | 1.62 | 39.3 | 0.41 | 3.48 | - |
| | 30 | 0.37 | 1.51 | 42.8 | 0.66 | 6.36 | - |
| | 43 | 0.65 | 1.27 | 51.0 | 2.5 | 12.4 | - |

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by

T.G. Boyadgiev

3.1. Introduction

The configuration of the relief of the arid and semi-arid regions of North Africa is characterized by extensive plains with gentle slopes belonging to the late Tertiary (Villafranchien) and to the recent Quaternary Age, called slopes (glacis). The old and middle slopes are gravelly marl; the more recent ones consist of fine clay material. These plains extend to the foot of the mountain chains.

The Hodna Basin is a typical example of this relief. Situated some 200 km due south-east of Algiers, separated from the Mediterranean by 150 km of mountains, it is surrounded by the mountains of Hodna to the north, the massif of Aurès to the east, the hills of Zab to the south-east and those of Ouled Naail to the south-west; it rises gradually to the west to the high Algerian-Moroccan plateaux.

Thus confined the Hodna Basin is subdivided (8) from north to south in the following physiographic regions:

- mountainous regions
- plains of Hodna
- Chott and the Sebkha
- the region of R'Uel (sand)

From the high to the low part, in a north-south direction, the pedogenetic characteristics and conditions change as follows.

The mountainous landscape, formed of limestone, marl and sandstone, of which the highest point is 1 745 m, descends to the foothills and to the plains (altitude around 800 m), made up of a succession of slopes, old, middle aged and more recent ones, to join the Chott and the Sebkha with deltaic deposits at an altitude of 391 m. In the region of R'Uel the landscape rises again to 850 m consisting of sand dunes and slopes associated with isolated hills and then it joins the Saharan Atlas mountains.

This upper semi arid climate has cold winters with an annual rainfall of 400 to 600 mm in the mountains of the north and becomes arid upper with temperate to cold winters and an annual rainfall of 200 to 400 mm in the plains. In the Chott and Sebkha and R'Uel regions the climate is lower, arid, with temperate winters and an annual precipitation of less than 200 mm.

The vegetation passes successively from forested to calcicole, gypso-calciferous, silty gypso saline, silty saline and hyper saline groups and disappears completely in the Sebka. In the south vegetation is psammophilous in association with other groups.

Groundwater is found at a depth of more than 40 m in the high parts of the Hodna basin and is almost at surface level in the Sebka. The mineral content of the water increases and salinization of the sulphate-chloride type becomes chloride-sulphate and chloride. In the N'Gaus valley the groundwater is not very deep and the water is rich in bicarbonate.

3.2. The soils of the Hodna

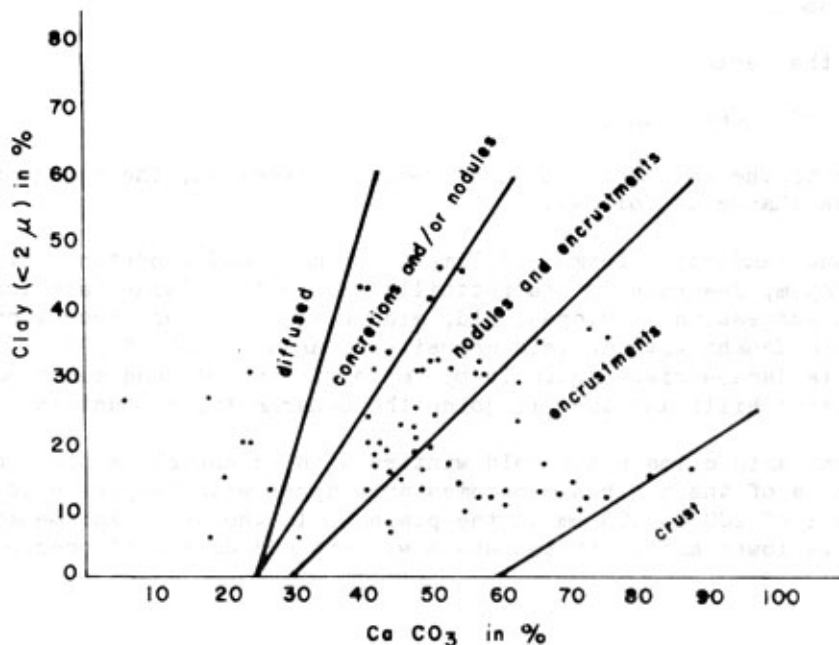
The major pedological processes in the Hodna basin are those responsible for calcimorphic, steppe, vertisol, gypsomorphic, halomorphic and desert formations. Erosion and alkalinity are equally noticeable.

The distribution of the Hodna soils is in relation to these phenomena and reflect the pedogenetic factors and conditions. Nevertheless, the accumulation and particular attributes of the gypsic limestones and soluble salts as well as the dune formations give the specific characteristics of the respective soils and landscape in the Hodna plains, the Chott, the Sebka and the region of R'Uel.

The accumulation of CaCO_3 in the soils of the Hodna plains and in the R'Uel is closely connected to its distinct formation.

It has been established that the form of CaCO_3 depends as much on the content as on the soil texture. This relationship is shown in Fig. 1. The following forms have been observed:

Figure 1 The relation between the calcium carbonate content and the clay content for different forms of lime



- calcareous crust (croûte calcaire)
- calcareous encrustation (encroûtement calcaire)
- calcareous concretions and/or nodules (amas et/ou nodules calcaires)
- diffused CaCO₃ (calcaire diffus)
- groundwater calcareous layer accumulation (accumulation du calcaire de nappe phreatique)

Each of these formations is linked with specific soil characteristics.

3.3. Soils with a calcareous crust

The calcareous crust is characteristic of medium textured Moulouyens and coarse textured Amiriens slopes. The CaCO₃ content is about 80-90 percent; it is found in the form of lamellar or non lamellar hard crusts. The thickness of the crust is from a few centimetres to more than a metre. The crust becomes less hard at depth and is sometimes overlaid by powdered lime.

The soils have an AC profile. The humous horizon is thin (from 8 to 26 cm), dark brown (7.5 YR 5/6) with a silt or loamy sand texture. The CaCO₃ content from 20 to 40% in the upper part increases sharply (80-90%) in the crust; sometimes between the A horizon and the crust there can be seen a horizon with calcareous nodules or with a crust of debris or encrusted debris, the calcareous content of which is 50-70%. The total of active CaCO₃ varies between 12 and 16% in the upper horizon and from 16 to 19% in the lower. The level of gypsum is negligible (<1%). The conductivity is normally below 2 mmhos/cm; certain profiles are lightly to moderately saline (from 2 to 10 mmhos/cm).

The A horizon contains about 1.5% organic matter with a C/N value of 9; the exchange capacity varies between 2 and 18 meq/100 g of soil and that of available P₂O₅ is 30 to 120ppm.

The soils have a capability index (7) of lower than 0.4 and are left for sheep grazing; in some areas they are suitable for cereal growing.

3.4. Soils with calcareous encrustation

CaCO₃ encrustations are linked with old and middle slopes (saletiens, amiriens et polygéniques). They are found in the form of a thin crust, non zonal and broken up, of tuff hardened or calcareous powder. The total CaCO₃ content varies between 50 and 80%.

It should be mentioned that the CaCO₃ is of a much more complex form. Accordingly a powdered horizon with tuffs can be found and sometimes a horizon with concretions and/or calcareous nodules above or below the encrusted horizon, sometimes the nodules fill the length of the profile, and sometimes there is a layer of narrow compacted bands and nodules; layers of gypsum have also been observed.

This great variety could be explained by the varying geomorphological positions as well as by the chemical and granular composition of the weathered products.

The soils have an AC profile. Their upper horizon is thin, about 12 cm, dark brown in colour (7.5 YR 5/6), with a polyhedral subangular structure that is fine or very fine grained and of a medium texture. The humous horizon lies over a gravelly one, which is encrusted and of a bluish colour (7.5 YR 8/2).

The total CaCO_3 content on the surface is an average 30-40% of which the active fraction is from 9 to 15%; the calcareous accumulation is between 40 and 100 cm deep. Occasionally, a second calcareous horizon can be seen about a metre lower and separated by a gypseous horizon. The content of active CaCO_3 in highly calcareous horizons is 11-18%.

The soils are either non gypseous across the profile or with one or two gypseous horizons in which the gypsum content is about 76%. The conductivity is normally less than 2 mmhos/cm in the upper part and from 2 to 7 mmhos/cm when deeper; the maximum conductivity observed is 32 mmhos/cm. The salinisation is the sulphate or chloride type with respectively $\text{Ca} > \text{Mg} > \text{Na}$ and $\text{Na} > \text{Mg} > \text{Ca}$.

The surface horizon has the following physico-chemical and chemical compositions: organic matter of about 0.9%, C/N of 8 to 12; T of 3 to 18 meq/100 g of soil; exchangeable K^+ of 0.2 to 0.8 meq/100 g; available P_2O_5 about 50 ppm.

Encrusted soils have a capability index below 0.4 and are used for sheep grazing. The surfaces which can benefit from shallow flood waters will grow cereal crops and give satisfactory results.

3.5. Soils with calcareous concretions and/or nodules

Concretions and/or nodules typify above all the middle slopes (tensiftiens). In terms of the texture, a CaCO_3 content of 10 to 60% gives rise to soft concretions often with a central core and isolated or composite nodules.

The soils have an ABC profile. The upper horizon is seldom thick (10 to 30 cm, rarely 60 cm), brown yellowish (7.5-10 YR 5/6), medium textured (mainly loam or loamy-sand) and with a polyhedral structure subangular medium to fine, lamellar on the surface. This horizon is calcareous (CaCO_3 of 15 to 40%) with an active lime content of 7 to 18%. The organic matter content is on the average 0.6 to 0.9% with a C/N ratio of 8 to 11; the exchange capacity oscillates between 13 and 23 meq/100 g of soil. The exchangeable K^+ is 0.4 to 0.8 meq/100 g, available P_2O_5 is 30 to 70 ppm, total P_2O_5 is 0.5 to 0.9%, Na/T is 5 to 20% and the pH is 7.7 to 8.1 which also typifies the A horizon.

The lime accumulation horizon, found immediately below the A horizon, goes down to 180 cm deep if it does not rest on a horizon of accumulated gypsum and ends at about 45-115 cm deep if it is overlaid by a gypseous horizon.

The CaCO_3 in the B horizon, of which the total is on average 40-60%, causes a hardening of the whole horizon. The numerous galleries and animal fossils which are typical of this horizon are also hardened, cemented by the limestone. The total active CaCO_3 is 14-17%.

The soils are either non gypseous across the horizon, or strongly gypseous (28-69) below the horizons of accumulated CaCO_3 . They are sometimes saline with a conductivity which reaches 14 mmhos/cm.

These soils are suitable for the growing of cereals and fodder. Their capability index is 0.4 to 0.6. The dryness of the soil, the hardened horizon and the high active CaCO_3 content are the limiting factors for plants.

3.6. Diffused CaCO₃ soils

This form of limestone is typical of the recent piedmont slopes (soltanien-rharbien) with a groundwater depth greater than 7 m. These slopes are intersected by watercourses with a depth of 5 m upstream which lessens progressively downstream. The CaCO₃ content is about 30%.

The soils are brown yellow (10 YR 5/4) with a polyhedral structure subangular medium to heavy textured and with a fine, lamellar layer on the surface. The CaCO₃ appears sometimes in the form of mycelium or as a few concretions; efflorescence, stains and gypso-saline channels are also noted.

The horizons are hardly distinguishable. The texture is medium to heavy with a stratification of grain size distribution (lithologic) at depth.

The rate of total CaCO₃ is constant across the profile or shows a slight rise at depth. The percentage of active CaCO₃ is from 11 to 14%. The gypsum content is negligible; conductivity is less than 8 mmhos/cm. Salinisation is of the sulphate-chloride type with a rise relative to the chloride in the upper part of the profile.

It is notable that on these piedmont slopes there have also developed soils with a horizon of accumulation of gypsum at depth as well as soils affected by soluble salts, which too have a diffused distribution of CaCO₃.

Diffused calcareous soils have the following chemical and physio-chemical characteristics: organic matter from 0.5 to 1.3% regularly or irregularly distributed over the whole depth; C/N 8 to 11, pH 7.8-8.0; T of 8 to 28 meq/100 g of soil, exchangeable K⁺ 0.5 to 1.0 meq/100 g; total K₂O of 3.7 to 7.1%, available P₂O₅ of 20 to 70 ppm, total P₂O₅ of 0.3 to 1.9% and Na/T of 5 to 15%. These soils are very good to good for dry farming and for irrigation with a capability index of 0.6 to 1.0. Their productivity can be raised by the practice of rational agriculture and all the more if they benefit from shallow floodwaters and from irrigation.

3.7. Soils with a groundwater calcareous layer accumulation

The accumulation of layered CaCO₃ has been observed on the recent slopes in the region of N'Gaous where the groundwater level is quite shallow (about 1 m) and the water is rich in bicarbonate.

The soils are of a greyish colour associated with reddish marks; the texture is medium to heavy and the structure polyhedral subangular.

These soils are heavily calcareous, of nondistinct form or with the inclusion of nodules; the CaCO₃ content is 60-70% equally distributed across the profile; the rate of active CaCO₃ is 14-19%. They contain no gypsum. The conductivity is below 2 mmhos/cm. The organic matter content is 2-3% in the upper part and diminishes evenly with depth. The C/N ratio is 7-10. There is a rise in exchangeable Na+K in the part over 75-90 cm. Their T oscillates between 8 and 18 meq/100 g of soil. The mineral amounts are: available P₂O₅ from 80 to 100 ppm; total P₂O₅ about 2%; exchangeable K⁺ 0.3-0.7 meq/100 g and total K₂O 3.7-4.2%. These soils have a capability index of about 0.6 and are now used for apricot orchards. Drainage would improve their capability index.

3.8. The place of the Hodna calcareous soils in the different classification systems

Without recalling the following classification concepts: U.S.A, French, Russian and FAO/Unesco for the soils of the semi-arid and arid region, we will attempt to classify the soils of Hodna according to the norms of these classifications.

The approximate correlation among the different classifications is given in Table 1.

Concerning this table one can make the following remarks:

U.S.A. classification: they classify in the same group soils with a calcareous encrustation and with concretions and/or calcareous nodules. To stress the importance of the horizon strongly enriched with CaCO_3 , it is necessary to introduce a new group which could be called Hypercalcic Calciorthods. These are the soils which are up to one metre deep, have a highly calcareous horizon which is typified by:

- a thickness of 15 cm or more
- CaCO_3 content above 40% if the clay content is below 10%, or is 60% and more if the clay content is 35% or more, or if the intermediate content of the clay has a proportionate percentage of CaCO_3 (see Figure 1)
- The form of the CaCO_3 - thin crust, non lamellar, broken up; hardened tuff; powdery

If a Gypsiorthod has this horizon the group would be a Hypercalcic Gypsiorthod.

A new group could perhaps also be proposed for the soils with an accumulation of layer limestone, to be known as Calcic Haplaquept.

Russian classification: the individualization of the limestone is not taken into consideration; a subdivision at least at the level of the brown-grey arid type of soils and of the sierozems is to be recommended.

French classification: in the present state, the French classification needs to be made precise concerning the difference between the brown calcareous soils and the sierozems, as well as the subdivision at the level of the sub-groups; new sub-groups corresponding to the different forms and characteristics of limestone should be recognized.

FAO/Unesco classification: the definitions of Yermosols and Xerosols need to be more precise. A precise definition could be based on the presence of:

- an accumulated horizon of gypsum in the part above 150 cm deep;
- conductivity above 2 mmhos/cm in the part at least one metre from the surface;
- aggregates with an extremely fine structure in the upper horizon.

The coarseness of the texture as well as the annual rainfall must also be taken into consideration.

The Yermosols are the soils developed in arid and semi-arid conditions with an annual rainfall of less than 400 mm and they have one or several of these characteristics. On the contrary, the Xerosols do not have these characteristics and are developed under humid conditions (rainfall greater than 400 m/year). The "pallid" horizon and an increase in exchangeable Na+K in that part above 75-125 cm from the surface characterises the Xerosols. They can have a calcic horizon but never a gypseous.

Table 1

Classification of the Calcareous Soils of Hodna

| Form of the CaCO ₃ in the part above one metre deep | American classification | Russian classification | French classification | FAO/Unesco classification | Zonal soils of Hodna |
|--|--|--|--|--|--|
| Crust | Xerollic and Typic Paleorthids | Brown-grey arid soils on hard limestone | Brown calcareous soils with CaCO ₃ encrustment | Calcic Xerosols and Calcic Yermosols petrocalcic phase | Sierozems with a calcareous crust |
| Encrustation | Typic and Xerollic Calciorthids Calcic Gypsiorthids | Sierozems on pebbles Brown-grey arid soils developed on gypsum 1/ | Brown calcareous soils with a calcareous encrustment | Calcic and Gypsic Xerosols Calcic Yermosols | Sierozems with a calcareous encrustment |
| Concretions | Typic and Xerollic Calciorthids Calcic Gypsiorthids | Pale Sierozems Brown-grey arid soils developed on gypsum 1/ | Encrusted Sierozems | Calcic and Gypsic Yermosols | Sierozems with concretions and/or calcareous nodules |
| Diffused | Xerollic and Fluv-entic Camborthids | Alluvial soils Sierozems with layers 2/ | Weakly developed soils with humic alluvial deposits | Haplic Xerosol | Modal Sierozems weakly developed soils. Steppic |
| Accumulation of calcareous layers | Typic Haplaquepts | Layered Sierozems Sazovie 3/ | Hydromorphic soils with a redistribution of calcareous nodules | Calcic Gleysols | Hydromorphic soils with an accumulation of calcareous layers |

1/ in Russian "podstilaemie gypsom"

2/ in Russian "lougovato sierozemnie"

3/ in Russian "sazovie lougovie sierozemi"

If this precision would be accepted, the unit Gypsic Xerosol could be suppressed.

A hypercalcic phase corresponding to the petrocalcic could also be suggested. These are the soils having a highly calcareous horizon, defined as the Hypercalcic Calciorthids.

To classify the zonal soils of Hodna at group levels, the following observations have been taken into account:

- the content and form of the CaCO_3 in the soils as it reflects the evolution of the country during the Quaternary age
- the presence of a crust the formation of which is continuing
- the presence of different forms of limestone in the soils, most of which are in association.
- the differentiation of the lime in soils with a coarse texture is more intense than in heavy soils
- the presence of different types of lime in hydromorphic environments.

Conclusions can be drawn from these observations which indicate a progressive evolution throughout Quaternary times in which the hydromorphy and thermo-dynamic conditions played an important role. The distinct forms of the CaCO_3 mark the different stages of the evolution of the soils.

On this basis the zonal soils of Hodna are classified using the French nomenclature on a level with the sub-class of Sierozems; the subdivision in groups is according to the degree of differentiation of the lime (see Table 1). The groups could be subdivided into the following sub-groups: typical, saline, gypsiferous with depth, vertic and wind eroded (1).

3.9. Conclusion

In the plains of Hodna it can be seen that there is a very close relationship between the soils, the piedmont slopes and the form of accumulation of the limestone. The nature of the weathered products, the depth of the groundwater, the chemical composition of the water, the texture as well as the thermo-dynamic conditions have played and are playing an important role in the semi-arid and arid conditions concerning the accumulation of calcium carbonate in the soils and its particular form.

Considering that the different stages of evolution of the soils are determined by the form of the limestone, the sierozems are classified at the level of a sub-class instead of a group.

The U.S.A., Russian, French and FAO/Unesco classifications should be perfected and/or made precise.

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by

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4.1. Introduction

There are three different climatic influences on the small territory of Bulgaria (111 thousand km²) situated in the eastern part of the Balkan peninsula: continental from the north, oceanic from the west and Mediterranean from the south. The high mountains (over 2 000 m) also affect the climate of the country. Stara Planina (the Balkans) divides the country into a northern and southern part respectively; it also restricts the cold air coming from the north, while Rila and the Rhodopes restrict the Mediterranean influence from the south. Thus there exist several climatic regions in the country with respective prevailing influences: moderate continental, transitory continental, continental Mediterranean, mountain climatic, etc.

Both the orography and geological structure in the country are rather complex. There are sedimentary, magmatic and metamorphic rocks. The most widespread sedimentary ones, are: loess, limestones, marls, sandstones, clays, etc, of the magmatic rocks the granites and andesites are the most widespread, and of the metamorphic ones, gneisses, schists, phyllites, etc. The variegated geological basis, the complex orography, the different climatic influences, the rich flora (over 3 000 plant species), the ancient agricultural management and other factors all contribute to the formation of a comparatively great soil diversity.

Calcareous soils are mostly represented by calcareous chernozems and rendzinas (humic carbonate) covering 10 percent of the country's territory, as well as by smaller areas of calcareous and typical smolnitsas, cinnamonic soils with rendzinas, brown forest soils with rendzinas, eroded chernozems, etc. The area covered by calcareous soils is smaller than that of the carbonate parent rocks, which is due to the fact that the leaching processes in the country are widely spread and therefore leached soils are very common. As regards arable land calcareous soils cover about one fifth of the country's territory.

4.2. Calcareous Chernozems

Calcareous chernozems are widespread in the northern part of the Danube plain; they are developed on loess, loess-like clays and marls, and cover about 0.72 million ha, being divided into two regions: along the Danube and around the towns of Shouman and Varna. They are differentiated, moderately thick on loess, slightly thick on loess-like soil-forming material, and skeleton ones on hard carbonate rocks and eluvium. The moderately thick ones with 40-80 cm deep humic horizon are the most widespread. No compaction of the transitory horizon is observed in these soils. The carbonate micelle is between 20 and 80 cm, but there are cases with the micelle found to a depth of 170 cm. Most of the calcareous chernozems are of a moderate sandy loamy soil texture. The content of particles smaller than 0.001 mm is about 22 percent, while in the loess, on which the soils

are formed, these particles are 12%. The amount of physical clay (particles smaller than 0.01 mm) is from 26-44% as regards the parent rock. A tendency is observed toward an increase of clay particles from west to east, which is related to the carrying away of soil material by the Danube river. The hydromicas, montmorillonites and kaolinites are the most widespread clay minerals prevailing in the calcareous chernozems. Humus content is not very high, about 2-3% in the soils cultivated for a long time. Humus of 25-35% is encountered in the one metre deep soil layer containing the arable soil layer. The humic acids and humins prevail in the humus. CaCO_3 content is not very high; it is usually from 1-3% and pH is about 7.5-8.0. Sorption capacity is mostly 20-30 meq/100 g of soil; exchangeable calcium cations prevail strongly (78-86%), while those of magnesium are 10-20% only, of potassium and sodium less than 5%. The total amount of P_2O_5 is 0.17%; the calcium phosphates also prevail strongly. The content of water soluble phosphates is very low. As a whole, the phosphorus status of calcareous chernozems is unfavourable because of the concentration of phosphorus in the coarse fraction of the soil and weak weathering of the phosphate minerals. These soils are well supplied with potassium. They have a positive reaction with nitrogen, phosphorus and zinc (e.g. with maize).

Calcareous chernozems have favourable physical properties, such as porosity and air permeability; they are not compacted along the depth of the whole profile. Water permeability and filtration are both comparatively high, which leads to an insufficient water balance. As a result of the continental steppe effect in the region there are often droughts irrespective of the fact that the mean annual amount of precipitation is about 600 mm.

4.3. Rendzinas (humic calcareous soils)

These soils are usually developed on hard limestone rocks in the four mountain and mountain regions of the country, while in the flat and hilly regions they are developed on diluvial, limestone clays, etc. They cover a total area of 0.304 million ha. The shallow rendzinas, 20-30 cm thick, that are often subjected to erosion are the most widespread. The rendzinas developed on ancient flood cones are of a thicker humus horizon. Rendzinas are connected with transitions with the zonal soils of the type of chernozems and cinnamonic forest soils. They are often dark brown and redbrown in colour.

Rendzinas are sandy loamy soils with a different skeleton.

The partial studies carried out on the composition of clay minerals have shown a certain dominance of montmorillonites, micas and kaolinite. They are loose, structured, aerated, with unfavourable water relationships. The content of humus in the rendzinas from the mountain regions is from 5-7%, while in those from the plains, from 2-3% only is accumulated mostly in the arable soil layer. The fulvoacids are less than the humic acids. The carbonates vary from several percent only to 40% in the arable layer, while in the subsoil arable layer they can even reach up to 75%; pH is usually about 7.5-8.0. Sorption capacity reaches, with some differences for a heavier soil texture, up to 35-45 meq/100 g of soil (the rendzinas from all regions in the country have not yet been studied).

The studies made on the forms of iron and aluminium in some of the rendzinas have shown an increased content of amorphous forms of iron and a decrease of silicates and especially their oxycrystal forms, and the high mobility of aluminium compounds. The last phenomenon differentiates the rendzinas from the cinnamonic forest and brown forest soils.

Rendzinas are poorly supplied by available forms of nitrogen and phosphorus and well supplied by potassium. They are poor in zinc and available iron. They also show a good response to nitrogen and phosphorus fertilizer application; residual effect of phosphorus is particularly good.

4.4. Some Problems in the Use of Calcareous Soils in Agriculture

Calcareous soils are intensively used in agriculture. Most of the main arable crops in the country (wheat, maize, sunflower, beets, vines, etc.) are grown on those soils in North Bulgaria. Hence the importance of all the practices that can improve fertility of these soils or restrict some of the unfavourable properties.

4.4.1. Calcareous Chernozems

Low water holding capacity and comparatively high soil permeability are among the unfavourable properties of the calcareous chernozems. With non irrigated lands very often the yields from the crops grown on these soils, particularly in the summer, are lower when compared to those from the leached chernozems situated in the same neighbourhood. The effect of fertilizers applied is also smaller, particularly for maize grown without irrigation. Thus, irrigation of calcareous chernozems is necessary to ensure the required water supply for the development of the crops, as well as for the increase of nutrient uptake. This has also been proved by the results obtained from field experiments as well as by agricultural practice. In the course of the last few years irrigation has been widely introduced with calcareous chernozems.

In order to improve the water holding capacity of calcareous chernozems experiments are being carried out with conditioners (polymers) with perlite, organic and other materials. Positive results have been obtained from experiments on small plots with the above quoted substances, though no recommendations can be made for practical purposes at this stage.

Improvement of the phosphate status of calcareous chernozems is an important problem. It has been established that when higher rates of superphosphates (the so-called "store fertilizer application") are applied to soils with a lower content of carbonates, a higher level of available phosphates is created which are not fixed irreversibly and can be used by plants. The increase in phosphate levels has raised the problem of the low supply of available zinc and boron with some crops (maize, alfalfa, fruit trees, etc.). To this end zinc fertilizers were widely applied recently; they have proved very efficient with the above mentioned crops.

Soil erosion control is another very important problem to be solved with calcareous chernozems in these regions.

4.4.2. Rendzinas

Rendzinas have been studied to a lesser extent than the chernozems. The data available show the requirement of nitrogen and phosphorus fertilizers to be introduced, as well as trace elements such as zinc and iron. Chlorosis is often met in these soils too. Vines, tobacco, arable crops, etc. are mostly grown on them.

Since rendzinas usually occupy the fore-mountain and hilly regions they are subjected to erosion. To combat this terraces can be made on small spaces, where the soils are thicker, e.g. on some deluvial deposits. Erosion control practices (grass buffers, re-seeding, etc.) are of great importance and can help to increase fertility, since they improve the nitrogen balance and production of protein.

Irrigation of rendzinas in flat regions has also proved efficient but has given rise to some difficulties due to relief, some technical problems and the hazards of erosion.

The following conclusions can be drawn from this brief review of the problems of calcareous soils and the improvement of their fertility. Studies should be conducted on:

- (i) the role of carbonates and their dynamics along the depth of the profile under the conditions of the country. Both type and size of the particles of the carbonate minerals should be studied in detail
- (ii) the effect of carbonates on mobility and availability to plants of phosphorus, zinc and other important major and trace elements
- (iii) efficient ways of improving the water holding capacity of calcareous soils
- (iv) the erodibility of calcareous soils and determination of the most important appropriate hydrotechnical and management practices as regards erosion control.

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VI. RECOMMENDATIONS

1. Exchange of information

The Seminar recognizing that calcareous soils are very extensive in the Near East Region and are a major resource for increasing agricultural production, recommended that FAO compile the information available on the effective use of these soils and secure an exchange of data between the countries of the region; it is further recommended that research still needed be conducted jointly by interested countries and FAO in the framework of the FAO/UNDP Near East Applied Research Programme.

2. Characterization of calcareous soils

With a view to making comparative studies of the use of calcareous soils in the region, it is recommended that the concept of calcareous soils be more precisely defined and that the description of these soils be expressed in standardized terminology. It is recommended that, in addition to usual field description and laboratory analysis, the amount of CaCO_3 , the form in which it is present and its distribution in the profile be recorded along the following lines:

a) Morphological characteristics

- i) Vertical and lateral variations of the distribution and accumulation of lime
 - diffuse distribution
 - discontinuous accumulation
 - pseudo mycelium
 - friable nodular
 - hard nodular
 - continuous accumulations (crusting)
 - non platy crusting with massive or nodular structure
 - platy crusting in the form of calcareous crusts or compact slabs
 - laminated crusting or ribboned pellicule (thin lime pan)
- ii) Vertical and lateral variations of lime content, and kind of carbonates (e.g. CaCO_3 , MgCO_3 , dolomite)
- iii) Texture of both the calcareous and non calcareous fractions of the surface horizons.

b) Physical and chemical characteristics

The morphological characteristics should be complemented by physical, chemical and mineralogical characterization. In addition to routine analyses the following characteristics should also be determined: the particle size distribution of the CaCO_3 and its activity, bulk density and strength - especially of the surface horizons, moisture characteristics, exchangeable cations and micro-nutrients, measurements of salinity and alkalinity, content and type of organic matter and composition of clay minerals.

3. Soil correlation

With a view to assessing the availability of land for development, it is recommended that the countries of the region pursue the survey of calcareous soils and that in order to allow for an exchange of experience, the classification system used for mapping be correlated using the FAO/Unesco Soil Map of the World legend as a common denominator.

4. Land use evaluation

With the mapping of calcareous soils it is required that the characteristics of importance for agricultural development be recorded. It is recommended, therefore, that the relationship between soil properties, morphological characteristics mentioned under No. 2 and their effect on crop growth, and soil and water management practices be established under specific environmental conditions and be used for land use evaluation purposes at different levels.

5. Soil testing

The Seminar noted promising results established by soil testing methods which have been developed recently, recommended that a comprehensive soil testing system be adopted for recommending fertilizer applications and that the calibration and interpretation of each test be checked under local conditions, with special reference to calcareous soils. The Seminar further noticed that there is a need for guidelines on standardization of analytical methods for calcareous soils and recommended that an expert panel be convened on this subject.

The residual effects of applied nutrients should also be studied through soil testing and the yield response of successive crops.

6. Research needs on P nutrition

Considering the following four factors which could be important to P uptake:

- a) the capacity factor which represents a measure of the amount of P from the solid phase that will enter the soil solution for a unit change in its P concentration,
- b) the intensity factor, usually expressed as the concentration of P in the soil solution,
- c) the diffusion coefficient of P in the soil or soil solution, and
- d) the demand for P by the plant top and the nature of the root system, i.e. its absorptive properties,

noting that some of the variables which control P uptake by plant roots can be combined in equations that describe the conditions existing when a nutrient diffuses to a root system, realizing that little information is available on how to measure the capacity factor and the diffusion coefficient of P in highly calcareous soils, it is recommended that:

- a) work should be carried out to determine changes in the capacity factor progressively with time according to the type of P fertilizers, and
- b) any further research on P nutrition with special reference to its economic application and on the interpretation of soil testing results should be carried out on the basis of new concepts on how soils supply P to roots.

7. Research needs on N nutrition

It is recommended that research be conducted on Nitrogen nutrition under cultivation with particular reference to the three following points:

a) Nitrogen losses

- Loss or transfer of NO_3 from applied fertilizers under irrigation and during periods of high rainfall, taking into consideration soil properties (depth, permeability, organic matter content, etc.) and the amount of N applied.
- Loss of N as NH_3 through volatilization, taking into account pH, CaCO_3 content, moisture content, temperature, porosity and texture, rate of nitrification, etc.
- Loss of N by denitrification in relation to organic matter, organic amendments, moisture content at various depths, aeration and pH.

b) Nitrogen balance under different crop rotations and form of fertilizers.

c) Nitrogen fixing organisms and role of azotobacter in N nutrition under rainfed conditions.

8. Research needs on organic matter

It is recommended that research be conducted on the role of organic matter in calcareous soils with regard to structural stability and availability of nutrients (especially P and micronutrients). Concurrently the most efficient method of application, amount, source and form of organic matter should be investigated.

9. Research needs on micronutrients

It is recommended that research be conducted on the supply and availability of micronutrients in calcareous soils with special reference to the critical levels that have been established for zinc, iron, manganese and copper which are respectively 0.5, 4.5, 1.0 and 0.2 ppm. Further work is required on the use of soil tests for boron and other elements in relation to levels of both deficiency and toxicity. Special consideration should be given to the relation between phosphorus and micronutrients.

10. Irrigation practices

The Seminar recognizing the importance of sound management of the soil and water resources in general and for calcareous soils in particular, and noting the specific properties of these soils and the role they have in affecting their productivity recommended that:

- in studying soil/water/plant relationships the CaCO_3 content and its particle size distribution be taken into account in determining the soil texture and that more investigations be carried out on the active fraction of CaCO_3 and its role in these relationships;
- irrigation practices should take into consideration the moisture characteristics, crusting sensitivity to slaking and compaction and morphological characteristics of these soils;
- investigations should be made on the crop response to moisture and its role in nutrient and salt movements and chlorosis;
- irrigation methods, other than the conventional ones, should be used whenever possible to avoid land levelling of shallow soils and to conserve soil and water resources;
- the use of low quality water on calcareous soils should be investigated with a view to determining the susceptibility of calcareous soils to secondary salinization.

11. Surface crusting

It is recommended that field treatments be investigated to prevent the problem of surface crusting. Applications of H_3PO_4 , for example, and other practices should be examined and if proved effective, equipment should be developed for their application at the time of planting.

12. Tilth

It is recommended that machinery needed for tillage and terracing operations be tested in relation to soil properties bearing in mind plasticity indices; special reference is made here to heavy equipment required for land reclamation and other land uses, including the breaking of lime crusts and hard pans. Furthermore, the economical feasibility of breaking lime crusts should be investigated in each case.

13. Suitability of crops

With a view to obtaining optimum yields on calcareous soils, it is recommended that crops and varieties be selected which are adapted to calcareous soil conditions; this adaptation of crops may, in many cases, be no less effective than the application of soil amendments. It is further recommended that the study and use of indicator plants grown on calcareous soils be encouraged in a similar way to those grown on salt affected soils.

14. Extension

It is recommended that in order to make full use of available knowledge on properties and management of calcareous soils, extension programmes be strengthened with the purpose of bridging the gap between farmers and researchers and keeping the farmers informed of recent developments. Research efforts should be aimed toward the solution of practical problems in field situations, using the basic theoretical and experimental research as a guide. Approximations should be devised to enable extension specialists to recommend water and fertilizer requirements for direct use by farmers.

15. Regional Applied Research Programme

The Seminar recognizing that the action needed for the implementation of its recommendations will require inter-country coordination, recommends that this implementation be carried out in the framework of the FAO/UNDP Near East Applied Research Programme and expressed the hope that this programme, which is now in its first phase, will be further developed with the support of the UNDP and that FAO use its good offices to expedite early action in this respect.

I. Procedural Matters1st DayMonday
27 NovemberTime

- 09.00 - 10.00 - Registration
- 10.00 - 10.45 - Official opening of the Seminar
- 10.45 - 11.00 - Break
- 11.00 - 11.15 - Election of Chairman, Vice-Chairman
and Drafting Committee

II. Genesis, Classification and morphology
of calcareous soils

- 11.15 - 14.00 - Genesis and distribution of calcareous
soils in the Mediterranean and desert
regions: Ruellan
- Distribution of calcareous soils in the
Near East Region, their reclamation and
land use measures and achievements: Kadry
- Morphology, mechanical composition and
formation of highly calcareous, lacustrine
soils in Turkey: de Meester

III. Chemistry and fertility of calcareous soils2nd DayTuesday
28 November

- 09.00 - 11.00 - Nutrient supply and availability in
calcareous soils: Olsen
- Response of crops grown on calcareous
soils to fertilization: Fuehring
- 11.00 - 11.30 - Break
- 11.30 - 13.30 - Reports on countries: Afghanistan,
Cyprus, Iran, Iraq, Jordan, Kuwait and
Lebanon

IV. Soil and Water Management3rd DayWednesday
29 November

- 09.00 - 11.00 - Some physical properties of highly cal-
careous soils and their related management
practices: Massoud
- Soil and water management practices for
calcareous soils: Jackson

3rd Day (cont.)

- Wednesday
29 November
- 11.00 - 11.30 - Break
 - 11.30 - 12.15 - Irrigation and drainage practices of the organic calcareous soils in the Ghab Project in Syria: Arar
 - 12.15 - 13.30 - Reports on countries: Libya, Pakistan and Qatar

V. Applied Research

4th Day

- Thursday
30 November
- 09.00 - 11.00
 - Reclamation and management of calcareous soils in the Arab Republic of Egypt: Ilgabaly
 - Problems of regional interest and suggested research programmes: Kadry, Aboukhaled, Arar
 - Progress Report on the Regional Applied Research Programme on Land and Water Use in the Near East: Aboukhaled
 - 11.00 - 11.30 - Break
 - 11.30 - 13.30 - Reports on countries: Saudi Arabia, Somalia, Sudan, Syrian Arab Republic and Yemen Arab Republic

5th Day

Friday
1 December

VI. Excursion

6th Day

Saturday
2 December

VII. Report

- 09.00 - 10.30 - Presentation and discussion of the Draft Final Report
- 10.30 - 11.00 - Break
- 11.00 - 12.00 - Continuation of discussion on the Draft Final Report

Closing Session of the Seminar.

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